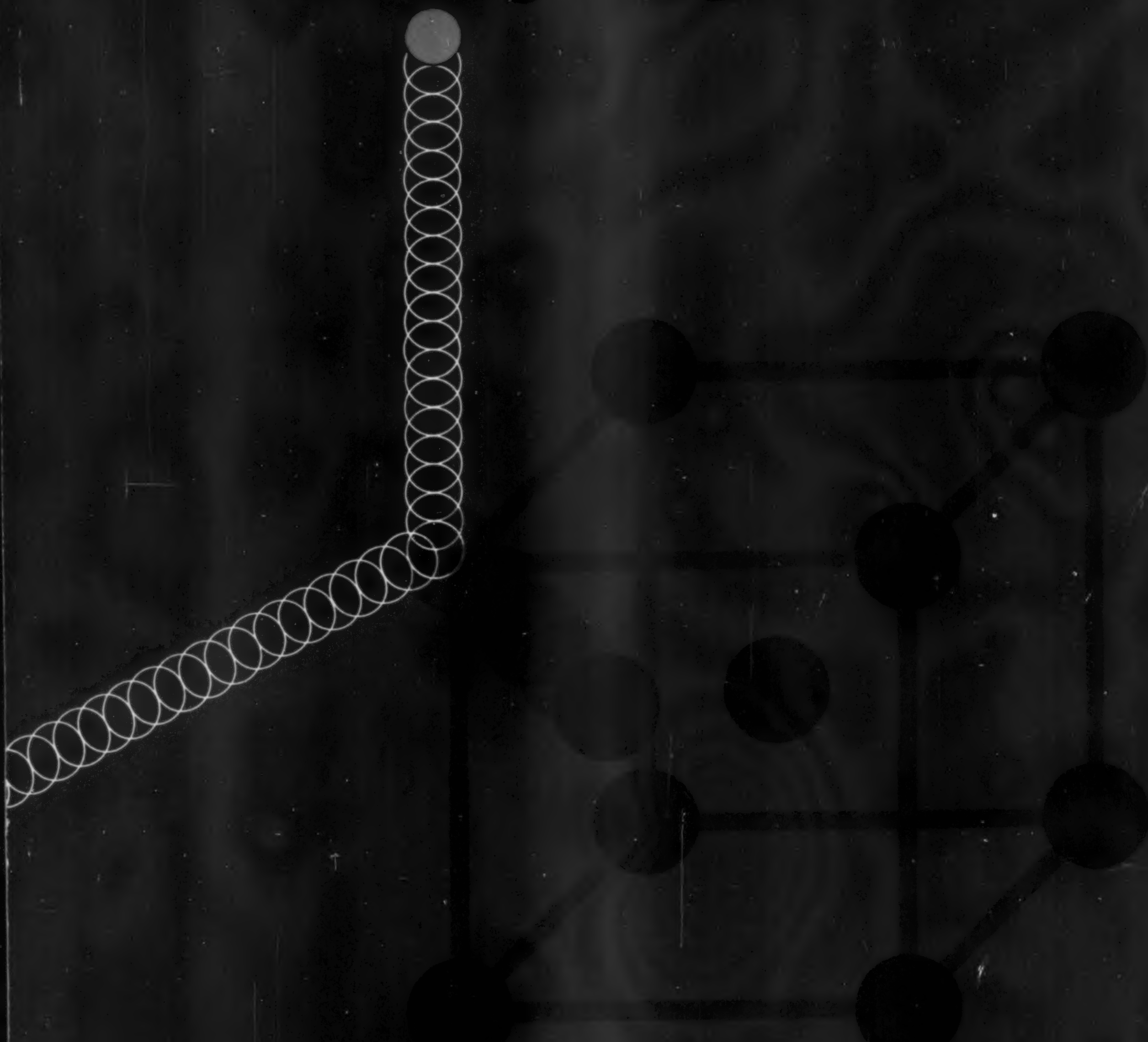
Materials in Design Engineering



How radiation affects engineering materials

[illegible] / Impact resistant plastics—page [illegible] / Complete contents—page 1

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JULY, 1960

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Materials
in Design Engineering

FORMERLY MATERIALS & METHODS

APPLICATION OF METALS, NONMETALLICS, FORMS, FINISHES

What's New in Materials

Engineering & Design

CONTINUED ON PAGE 3 →

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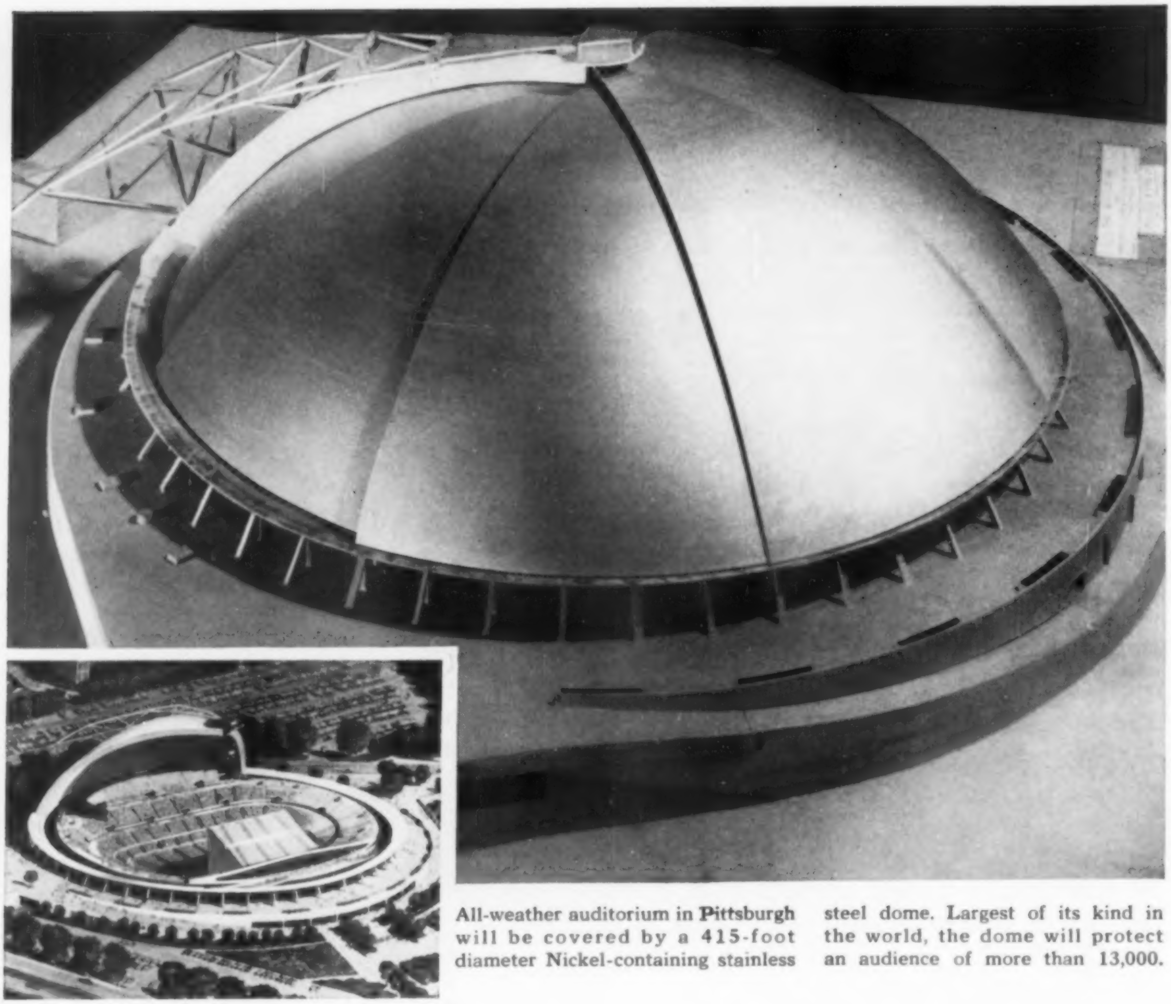
CONTINUED FROM PAGE 1

NEXT MONTH

Filament Winding: A Special 20-Page Report on Materials, Design and Evaluation
Split Die Forgings
Chromate Conversion Coatings for Appearance, Protection, Electrical Conductivity
How to Specify Optimum Tolerances for Sheet
Choosing Alloys for . . .
- *High Temperature Compression Springs*
- *Precision Resistors*

ASTM Changes Gray Iron Spec to Include Section Size
Weldability of Metals Rated by Process



All-weather auditorium in Pittsburgh will be covered by a 415-foot diameter Nickel-containing stainless steel dome. Largest of its kind in the world, the dome will protect an audience of more than 13,000.

"Push-button umbrella roof" of stainless steel gives Pittsburgh a new all-weather auditorium

Watching a play or listening to music under the stars heightens the enjoyment. That is, until a passing shower comes along to wash out the fun. But now comes a new idea in auditoriums. In this one, an umbrella roof of Nickel-containing stainless steel will close at the first drops of rain—and on with the show.

It's a simple concept, but a daring one. Eight huge sections nest together when the dome is open. Push a button, and six of these sections glide quietly together around an outside track.

They looked into all sorts of sheathing materials in designing the dome before choosing stainless – a Nickel-containing stainless steel.

For stainless with Nickel in it is one of the most weatherproof metals there is. It is corrosion-resisting all the way through – in salt air as well as industrial atmospheres. What's more, it's virtually self-cleaning – rainfall alone keeps this metal clean.

No wonder you see Nickel-containing stainless wherever strength, long life and handsome appearance are called for! Not only in buildings – inside and out – but everywhere you look.

Suggest something to you? Can stainless help you solve a problem involving corrosion, stress, appearance, temperature extremes? The way to find out is to write us. We'll see if Nickel-containing stainless steel – or some other nickel alloy – may be just what you're looking for.

THE INTERNATIONAL NICKEL COMPANY, INC.

67 Wall Street INCO New York 5, N. Y.

INCO NICKEL

NICKEL MAKES ALLOYS PERFORM BETTER LONGER

What's new IN MATERIALS

...AT A GLANCE

Structural ceramic fibers of virtually any oxide can now be produced. Pure alumina single crystal fibers can be produced in lengths up to ½ in.; they have ultimate tensile strengths of about 4 million psi and are useful at temperatures up to 3700 F. Also, polycrystalline fibers of any oxide can be produced in lengths up to about 8 in. Although not as strong as single crystal fibers, polycrystalline fibers provide versatility in other properties such as heat resistance and inertness to various matrices. Oxides used to date include zirconia, beryllia, silica and iron oxide.
Source: Horizons Inc., 2905 E. 79th St., Cleveland 4. Ceramic fiber production has just been licensed to Minerals and Chemicals Corp., Menlo Park, N. J.

Metals reinforced with these ceramic fibers (see above) are under development. Purpose: reinforced metals combine high strength and light weight. Castings compounded from 50% ceramic fiber and 50% metal weigh considerably less than all-metal castings of identical mass. A promising combination is an 80 nickel-20 chromium alloy reinforced with single crystal aluminum oxide fibers.
Source: Horizons Inc., 2905 E. 79th St., Cleveland 4.

A wear resistant coating for service up to 1800 F has been developed. The coating, a chromium carbide-base material, is applied by flame plating techniques.
Source: Union Carbide Metals Co., Div. of Union Carbide Corp., 30 E. 42nd St., New York 17.

Improved metal-to-alumina seals for use in electrical devices can be obtained by using a new iron-nickel-cobalt alloy that has a coefficient of thermal expansion closely matching that of alumina. The developer says that until now it has not been possible for the electrical industry to take full advantage of the high strength, high heat resistance, and excellent insulating properties of alumina. The new alloy is expected to permit the use of alumina in electron tubes, thermionic energy converters, capacitors and switchgear. (More details in a forthcoming issue.)
Source: General Electric Co., Schenectady, N. Y.

Permanent, vacuum-tight glass-to-metal seals may be realized by using a new vacuum melted alloy, composition of which has not been revealed. The developer says the alloy is metallurgically cleaner, has greater ductility, and has a better surface than other alloys used for glass-to-metal applications. The alloy's coefficient of thermal expansion is said to closely match that of hard glasses such as Corning's 7052 and 7040.
Source: Driver-Harris Co., 201 Middlesex St., Harrison, N. J.

Newly developed tin-coated stainless steel wire is said to offer excellent soldering characteristics when used for banding electric motor armatures. The wire is supplied in diameters from 0.031 to 0.105 in.
Source: Riverside-Alloy Metal Div., H. K. Porter Co., Inc., Riverside, N. J.

An improved solid film lubricant is said to have about 20 times more load bearing capacity than conventional solid film lubricants. The improvement was achieved by adding various inorganic sulfides to molybdenum or tungsten disulfide. When used

For more information, turn to Reader Service card, circle No. 325

to lubricate iron or steel surfaces, the additives apparently decompose to produce a layer of iron sulfide on the metal surface. The lubricant is still under development.
Source: General Electric Co., Schenectady, N. Y.

Aluminum die castings that can be color anodized are commercially available. According to the developer, colors can be accurately controlled from batch to batch, and can be applied over satin, polished bright, and semigloss matte finishes. The die castings are made of a new alloy (composition not revealed) that is said to have tensile and yield strengths comparable to those of standard die casting alloys.
Source: Hamilton Die Cast Inc., 240 N. B St., Hamilton, Ohio.

Lower cost platinum-plated parts may result from the development of a new anode made of titanium mesh and coated with a uniform thickness of platinum. The product is said to be functionally equal to solid platinum, but cost less than 1/10th as much.
Source: Sel-Rex Corp., 75 River Rd., Nutley 10, N. J.

Higher stress-rupture properties are now available in a relatively new cobalt-tungsten superalloy called WI-52. The producer says stress-rupture life and stress-rupture elongation values have been doubled by controlling chemical composition. The improved alloy is supplied in the form of shot specifically prepared for remelting.
Source: Wai Met Alloys Co., 5320 Oakman Blvd., Dearborn 2, Mich.

High temperature polymers that are stable at 1000-1800 F and have moldability similar to that of phenolics have been reported in England. The developmental polymers are believed to be lithium polyphosphates. Specimens have shown flexural strengths of 23,000 psi at 1000 F; 18,000 psi at 1800 F. Although said to be more like ceramics than plastics, the materials are tougher than ceramics.
Source: Artrite Resins Ltd., 44-46 Kingsway Rd., London, W. C. 2.

Finer grained sheet steel and strip has been produced by using a new continuous annealing process in which small sections of a metal coil are heated by induction. Grain sizes are reported to be one-fifth to one-third smaller than those produced by conventional annealing practices. The developer says the method can also be used to anneal brass, copper, aluminum and other metals.
Source: Allegheny Ludlum Steel Corp., Oliver Bldg., Pittsburgh 22.

A tungsten-lead radiation shielding material is said to withstand temperatures up to 1000 F. The new material has C24 Rockwell hardness, 19,000 psi tensile strength, and 25,000 psi compressive strength. It is supplied in a variety of shapes.
Source: Kulite Tungsten Co., 1040 Hoyt Ave., Ridgefield, N. J.

High purity gold powder and sheets are now commercially available. Purity of the gold is said to be 99.999%. A big use for the gold will probably be in joining silicon transistors, diodes and rectifiers. The powder is supplied in 100 mesh or finer; sheets are supplied in widths up to 4 in., in thicknesses down to 0.0005 in.
Source: High Purity Metals, Inc., 340 Hudson St., Hackensack, N. J.

Turn to page 9 for more "What's New in Materials"

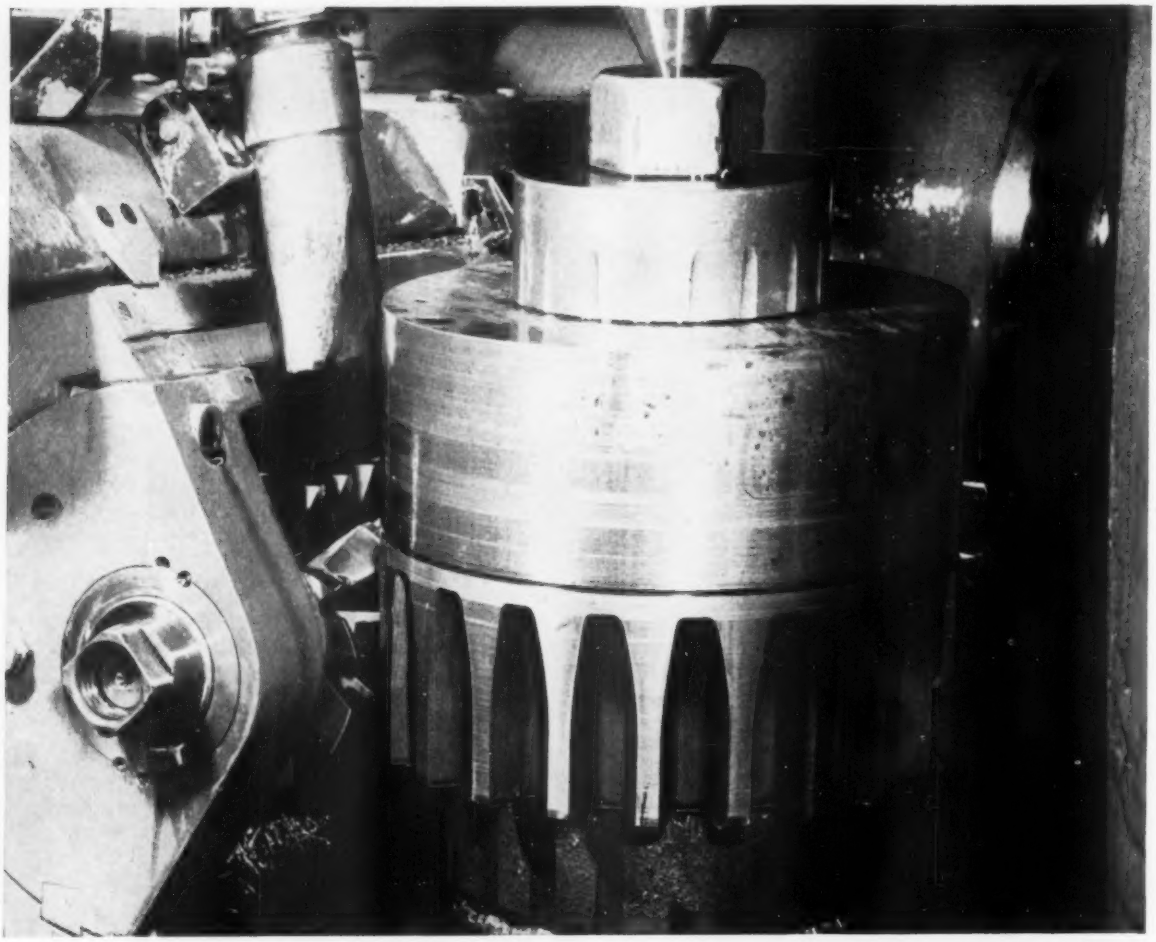


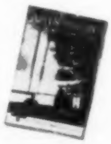
Photo courtesy Boston Gear

Aristoloy Leaded increases hob speed 50%... prolongs tool life 50% for Boston Gear

Together these add up to 100% satisfaction with Aristoloy Leaded* steel. By switching to Aristoloy Leaded, Boston Gear now machines three 7" Spur Gears per hour. Best production achieved on the steel previously used was two per hour.

With Aristoloy Leaded, 24 gears are cut before the hob needs sharpening . . . only 16 were possible with other steel used by Boston Gear.

Strength and hardness of the finished part show no detectable difference in physical properties from the unleaded steel used earlier.



For complete information about Aristoloy leaded or standard analyses carbon, alloy, and stainless grades, write for booklet entitled, "A Complete Line of Leaded Steels," and new Products and Facilities Catalog.

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For more information, turn to Reader Service card, circle No. 379

New Rigid Vinyl Resin Maintains Strength at 180-200 F

■ A new rigid vinyl resin—polyvinyl dichloride—boosts the heat resistance of vinyl plastics by about 40–60 F. The new material combines 180-200 F continuous heat resistance with the inherent chemical resistance, toughness, non-flammability and solvent-cementability of PVC (polyvinyl chloride). The material's 264-psi heat distortion temperature is in the range of 215-220 F, compared with about 140-170 F for rigid PVC, and about 130-150 F for molding and extruding grades of polyvinylidene chloride (saran). The new material also has a high modulus, providing good self-supporting characteristics.

TABLE 1—TYPICAL PROPERTIES OF RIGID POLYVINYL DICHLORIDE[a]

Properties ⬇	Normal Impact	High Impact
Ten Str, 1000 psi		
At 73 F	8.8	7.8
At 212 F	3.0	2.0
Ten Mod of Elast, 10^5 psi	4.5	3.9
Elong at Yld, %	4.5	4.5
Flex Str, 1000 psi	17	14.5
Izod Impact Str, ft-lb/in. notch	0.8	5.0
Rockwell Hardness	R117	R117
Heat Dist Temp (264 psi), F	220	215
Flammability	Self-ext	Self-ext
Specific Gravity	1.5	1.5
Coef of Ther Exp, 10^{-5} per °F	3.9	4.4

[a]Hi-Temp Geon, B. F. Goodrich Chemical Co.

Types available

According to the developers, B. F. Goodrich Chemical Co., 3135 Euclid Ave., Cleveland 15, Ohio, the new material called Hi-Temp Geon, is available in both normal impact and high impact grades, corresponding to Types I and II PVC. It can also be plasticized for flexibility.

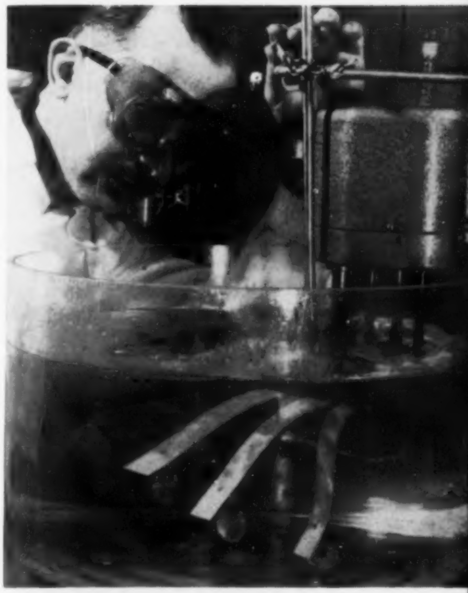
Properties of the normal and high impact grades are shown in Table 1. Resistance to chemicals is shown in Table 2, where data show results of complete immersion at 212 F in various reagents. More details on effects of temperatures and aging are unavailable as yet.

Preliminary tests are also reported to show the material to have exceptional resistance to light and weathering. According to one report, stability is three to four times that of uncompounded PVC.

The material is currently available in limited quantities at an introductory price of 45-60¢ per lb. Commercial availability is expected in 1961, but no estimates are available on commercial price range.

TABLE 2—EFFECT OF CHEMICALS ON RIGID POLYVINYL DICHLORIDE
(After 28 Days Immersion at 212 F)

Reagent ⬇	Weight Change, %		Tensile Strength, 1000 psi		Tensile Modulus, 10^5 psi	
	Normal-Impact	High-Impact	Normal-Impact	High-Impact	Normal-Impact	High-Impact
None (original properties)	—	—	8.8	7.8	4.5	3.9
Sulfuric Acid (93.5%)	−0.8	4.5	8.7	6.1	5.0	3.0
Chromic Acid (50%)	0.2	0.4	9.4	8.5	4.3	3.8
Sodium Hydroxide (50%)	−0.02	−0.07	9.9	8.4	5.7	4.8
ASTM Oil No. 3	0.4	1.2	9.8	8.3	4.3	4.1
Sodium Chloride (saturated)	0.7	1.2	8.5	8.3	4.1	3.7



***Heat resistance** of the new material is shown in this comparison of four weighted strips of plastics immersed in 180 F water. From left, the specimens are the new vinyl, nylon, high density polyethylene and conventional PVC.*

Pipe a prime market

The size of the potential market and the properties of the new material pretty clearly pinpoint plastic pipe as a prime applications area. For residential plumbing the material offers the required heat resistance, and non-flammability; for chemical piping it provides resistance to both heat and chemicals. In addition to these characteristics it provides the benefits inherent in vinyl pipe of being solvent cementable, lightweight and easy to fabricate.

According to Goodrich, the material can safely handle 125-lb pressure at 185 F in Schedule 40 pipe. Also, it maintains good

mechanical strength while carrying hot fluids, making it suitable for use as rigid piping, or ducts capable of spanning normal distances between building supports. Pipe can be joined with either socket type solvent-welded joints, or threaded fittings.

Although the producer's initial emphasis is on use of the material for pipe, broader applications are predicted. Automotive applications, where temperatures may reach 180 F would be one possibility. Uses in the electrical appliance industry, where nonflammability is critical, but conventional PVC has been unusable because of insufficient heat resistance, would also appear promising.

For more information, circle No. 600

New Brass Resists Algae Growth

■ An alloy has been developed by Bridgeport Brass Co., Bridgeport 2, Conn., for condenser and heat exchanger applications where fresh or saline waters support the growth of algae. Named Alloy 77, it is an inhibited copper-zinc alloy with a nominal composition of 70% copper, 30% zinc and 0.05% mercury. The mercury addition gives the alloy unusual resistance to biofouling and dezincification as well as good resistance to other forms of corrosive attack.

Service tests with Alloy 77 show that water deposited scale is thin and easily removed by mechanical cleaning. Tests also show that a lower concentration or less frequent and shorter chlorination periods are required to keep the tubes clean.

Condenser tubes of Alloy 77 are supplied in accordance with the requirements of ASTM Spec. B111 (with the exception of the chemical analysis which does not apply).

Alloy 77 is currently available in condenser tube sizes ranging from 5/8 in. o.d. to 1 in. o.d., and in wall thickness ranging from 0.049 in. (18 BWG) to 0.065 in. (16 BWG). It is available in other tube sizes as well as in regular pipe sizes. For uses other than condenser or heat exchanger applications the alloy can be obtained in tubes with thickened centers for return bend (U tube) or as dual gage tubes for applications where thinning of inlet ends is a problem.

For return bend (U tube) or as dual gage tubes for applications where thinning of inlet ends is a problem.

For more information, circle No. 601

Precision Aluminum Extrusions *from Powder Metallurgy Slugs*

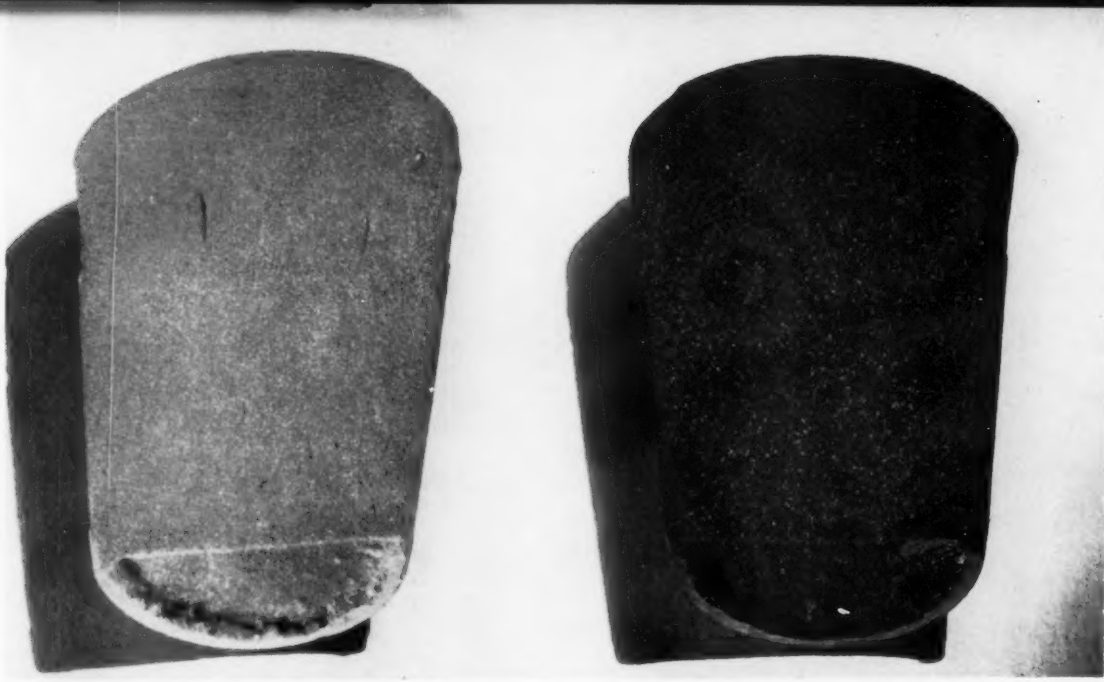
■ Aluminum Co. of America, 1501 Alcoa Bldg., Pittsburgh 19, Pa. recently announced a new process—called Alcoa APM Impacts—for the production of precision aluminum parts for high temperature service in the 800 F range. One prototype part fabricated by the new process is a 1/4 in. dia finned tube, impacted in lengths up to 14 ft, with wall thickness tolerance of 0.003 in.

***Finned tube** is produced by impact extrusion of an APM impact slug (hollow cylinder, center). Three other prototype parts are also shown.*
Aluminum Co. of America

The process works as follows: A powder metallurgy billet is pressed, sintered and compacted. The billet is then extruded to produce bar stock which supplies the slug for impact extrusion. As a result, upper operating temperature is boosted from 500 F obtained with normal impact operation to 800 F for the high strength parts fabricated from the APM slugs.

The process is now beyond the experimental stage. The finned tube prototype is being evaluated for an atomic energy application. Up to ten fins have been incorporated in the 1/4 in. dia tube and some tubes have been fabricated with spiraling exterior fins. The accompanying photograph shows the APM impact slug along with sections of the finned tube and three other Alcoa APM impact prototype parts. Alcoa will quote prices for commercial production of APM impacts.

For more information, circle No. 602



Infusible foam *before and after curing for 1½ hr at 400 F. There was negligible shrinkage and weight loss.*

Developments in High Temperature Urethane Foams

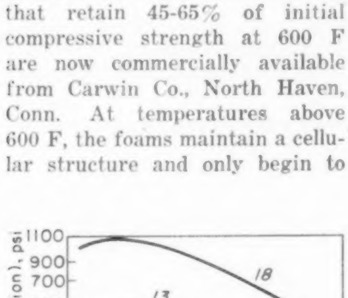
Both rigid and flexible systems are now commercially available. They are infusible, and maintain substantial strength at 600 F.

■ Rigid urethane foam systems that retain 45-65% of initial compressive strength at 600 F are now commercially available from Carwin Co., North Haven, Conn. At temperatures above 600 F, the foams maintain a cellular structure and only begin to carbonize at 900-1000 F. Above this temperature they sublime, and do not revert to a liquid or plastic state.

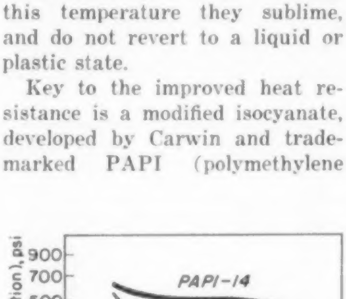
Key to the improved heat resistance is a modified isocyanate, developed by Carwin and trademarked PAPI (polymethylene polyphenyl-isocyanate). Preliminary data on experimental foam systems using the material were given by *D'Ancicco* in early '58.

Two complete foam systems are now available from Carwin: Carthane 1008 Infusible Foam, and Carthane 1003 Slow Foam. The two have identical properties, but the slow foam provides a controllable pot life of 5-12 min for foaming in intricate molds.

Systems are available for foams ranging in density from 3 to 40 lb per cu ft. Price for the two-component systems is about $2.50 per lb in carload quantities. Flexible systems are also said to be available. (PAPI is also available alone for those desiring to develop their own formulations. Cost: $2.25 in drum quantity.)



1—*Retention of compressive strength at increasing temperatures is shown for 6 foam densities.*



2—*Here's how the new PAPI foams compare with conventional TDI urethane foams.*

Properties of rigid foam

Table 1 shows typical mechanical properties of foams of different densities at different temperatures. Fig 1 shows effects of temperature on compressive strength at 10% deflection of

foams of various densities; Fig 2 compares temperature vs compressive strength for PAPI and conventional TDI urethane foams.

At temperatures between 450 and 500 F, chemical and physical changes occur in the foam, resulting in some weight loss and a corresponding shrinkage. However, as shown in Table 1, this reaction does appear to increase the foam's compressive strength at 500-600 F. Possibly this increase is due to the larger volume shrinkage experienced at these temperatures.

Dielectric properties of the foams are shown in Table 2. Although data on volume resistivity are limited, resistivity of a 3 lb per cu ft density foam is reported to be 2.15×10^{14} ohm-cm.

Foams are also said to have good resistance to humidity, maintaining strength, dimensions and weight under humid aging conditions. No appreciable change in compressive strength occurs after 7 days at 100% relative humidity and 158 F. Less than 0.5% change occurs in dimension or weight after 5 wk exposure in a Tenney cabinet (cycles between 120 and 50 F at 95% relative humidity, holding for 2 hr at each temperature). Other characteristics of the rigid foam, according to Carwin, include:

- Thermal conductivity (k factor) is said to be 0.26 for 3 lb per cu ft foam at 325 F.
- Postcured foams are resistant to oils, fungus, salt air and sunlight. Specimens of cured foam partially immersed in moist fertile soil for 6 summer months show no appreciable change.
- Absorption of impact loading and vibration are said to be excellent.
- Exposure to oxidizing torch results in carbonization of the foam, but retention of cell structure, followed by gradual vaporization; thermal insulating properties are retained during oxidation of the surface.
- Bonds formed with metals are stronger than the foam under long-term humid aging conditions.

TABLE 1—TYPICAL PROPERTIES OF RIGID FOAM[a]

Density, lb/cu ft →	5	10	18
Compr Str (at 10% defl), psi			
At 72 F	65	210	1045
At 225 F	64	190	895
At 325 F	50	175	650
At 400 F	40	160	450
At 500 F	48	175	820
At 600 F	30	110	680
At 1000 F	Carbonizes		
Ten Str, psi			
At 72 F	58	180	290[b]
At 225 F	53	130	175[b]
At 325 F	33	120	140[b]
At 400 F	22	110	130[b]
Compr Set (158 F), %	4.5	4.9	5.3[c]

[a]Carthane 1008; postcured 8 hr per in. foam thickness. at 400F.
[b]14 lb/cu ft density.
[c]13 lb/cu ft density.

TABLE 2—ELECTRICAL PROPERTIES[a]

Density, lb/cu ft →	4	8	14
Dielec Const			
1 mc			
At 80 F	1.04	1.14	1.30
At 212 F	1.04	1.15	1.31
At 390 F	1.06	1.18	1.37
8.5 kmc (77 F)	1.09	1.15	1.31
Dissip Factor			
1 mc			
At 80 F	0.0018	0.0032	0.0055
At 212 F	0.0016	0.0030	0.0048
At 390 F	0.0020	0.0043	0.0071
8.5 kmc (77 F)	0.0018	0.0024	0.0037
Loss Factor			
1 mc			
At 80 F	0.0019	0.0036	0.0072
At 212 F	0.0017	0.0035	0.0063
At 390 F	0.0021	0.0051	0.0097
8.5 kmc (77 F)	0.0020	0.0028	0.0048

[a]Carthane 1008; postcured.

Potential applications

The heat resistance of the foam indicates a number of potential uses. These range from missiles and aircraft where skin temperatures are high, to potting of electrical components where elevated temperatures are anticipated. The bond strength of the foam to metal would indicate its use as foam cores for structural honeycomb sandwich materials. Good thermal insulating characteristics would make the material useful for hot line insulation.

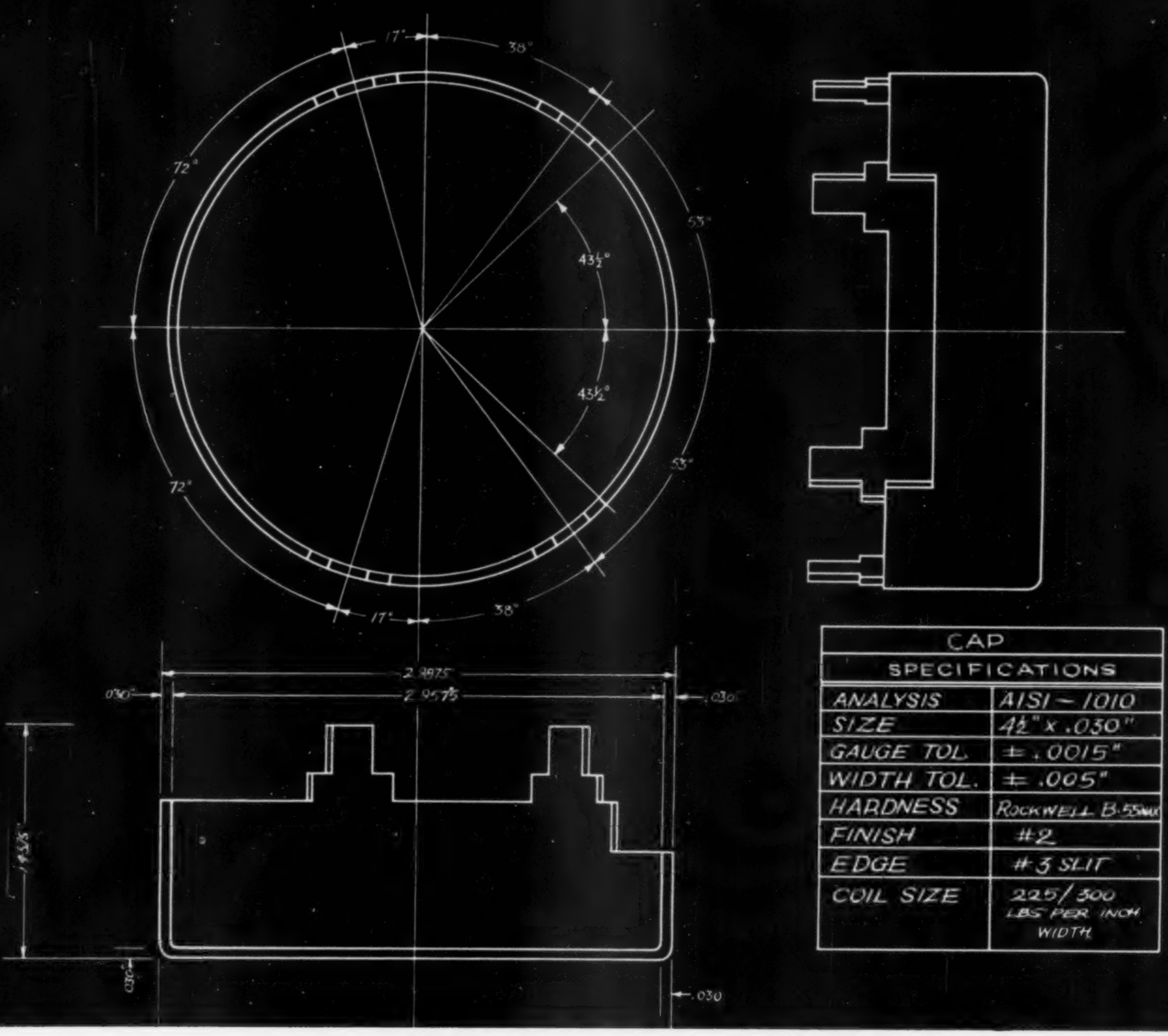
The infusible nature of the material up to complete degradation temperatures enable the foams to provide superior insulating properties under extreme thermal conditions. Possible uses as ablative insulation for rockets and missiles are obvious.

Reference

D'Ancicco, V. V., "A New Family of Heat Resistant Urethane Polymers," *SPE Journal*, Vol. 14, No. 2, Feb '58.

For more information, circle No. 603

MORE WHAT'S NEW IN MATERIALS



HOW CLOSE SHOULD THE TOLERANCES BE HELD?

This part may be produced in a ten-stage, progressive stamping die. It will be made from 0.030" low carbon cold rolled strip steel. The normal gauge tolerance is 0.0015" . . . or, a total variation of 0.003".

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Of course, tolerance should be no tighter than necessary for the successful design of the finished part . . . or for efficient, trouble-free stamping. If the part cannot be fabricated with a minimum of production trouble, the tolerance is *not* tight enough . . . regardless of the design requirements of the finished part. In an intricate, high speed stamping operation, a variation of 0.003" could easily result in a high percentage of rejects; could cause frequent down-time . . . constant tool adjustment; could create *needless* production problems.

Why not check your own stamping operation?

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The experience, facilities and accumulated know-how of a specialized organization . . . directed exclusively to the processing of low carbon, high carbon, alloy, tempered and stainless strip steels . . . are available to work for you. For assistance in solving your problems, call your J&L Stainless and Strip Division representative, or write to Dept. 235Y-714.

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High temperature plastics

To the Editor:

In reviewing your presentation of my article "High Temperature Plastics: Where Do We Stand?" (M/DE, June '60, p 132), I note several errors in your presentation of my thermal stability data as shown in the bar graph on p 133. The correct values should be as follows:

CFE fluorocarbon 400 F
Epoxy (pyromellitic anhydride) 500 F
Epoxy VC 8359 500 F

Also, the data on the "research and development" type of polymers mentioned in the chart apply to short term stability tests and do not belong under your heading "for 200 hr + service."

Gremlins must have come to your printer and worked overtime.

DR. WALTER BRENNER
New York University
College of Engineering
University Heights
New York 53, N. Y.

We had intended to imply that the research and development-type polymers mentioned in the bar graph were "aimed" for long time service. We agree that someone, who shall be nameless, tampered with the data. We reported on the 500 F capabilities of the VC 8359 epoxy only last April (p 17).

Corrosion properties of materials

To the Editor:

Could you tell me why you discontinued the corrosion tables in your Materials Selector issue?

(GHR)

There was so much controversy about the corrosion tables that we decided to discontinue them. Many corrosion authorities believe that general corrosion tables do more harm than good because the effects of all variables are not considered. The same critics say that there are too many engineers and designers who take the data at face value without verifying it themselves.

We are constantly studying this problem, and it is possible that we may again include corrosion tables in a future issue of the Materials Selector.

To the Editor:

Would you be able to help me select the proper metal for use under various corrosive conditions? For example, what percent of its tensile strength does aluminum alloy 2017-T4 lose after exposure to a rural atmosphere for five years?

Corrosion properties of other materials that I would be interested in include SAE 1020 steel; magnesium, free-cutting brass; commercial bronze; 7075-T6, 2024-T4, 6061-T6, 5052-H34 and 3003 alu-

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minum alloys; yellow brass; types 303, 304 and 416 stainless steel; K Monel; ETP copper; and 2% beryllium copper.

Most information on corrosion of metals seems somewhat vague because the data state that corrosion resistance of a particular material is "excellent," "very good," "fair" or "better than copper." What I would like is something specific.

What would be nice is a series of corrosion tables on common materials based on loss of tensile strength under various conditions for 1, 5, 10 and 20 years of exposure.

S. Konz
Collins Radio Co.
Cedar Rapids, Ia.

For specific information on corrosion resistance we suggest contacting suppliers of the various metals. An excellent source of information is International Nickel Co., 67 Wall St., New York City. This company has been determining the corrosion properties of materials under various conditions for many years and maintains an extensive file.

Comments on metal fracture article

To the Editor:

I found the article "Why Metals Break and What to Do About It" very interesting and well presented. I might suggest that following articles could logically be concerned with the fracture of ceramics and brittle metals, with particular attention being given to design considerations such as size, time, surface conditions, grain size, temperature, etc.

J. Gurland
Associate Professor of Engineering
Brown University
Providence, R. I.

To the Editor:

I have just read the article "Why Metals Break and What to Do About It" (M/DE, Apr '60, p 127). It is a good article, and I enjoyed reading it.

However, I would like to point out that the captions under the two fractographs on page 136, which show an intergranular and a cleavage fracture, have been reversed.

R. C. Bates
Materials Engineering Depts.
Ferrous Application Group
Westinghouse Electric Corp.
East Pittsburgh, Pa.

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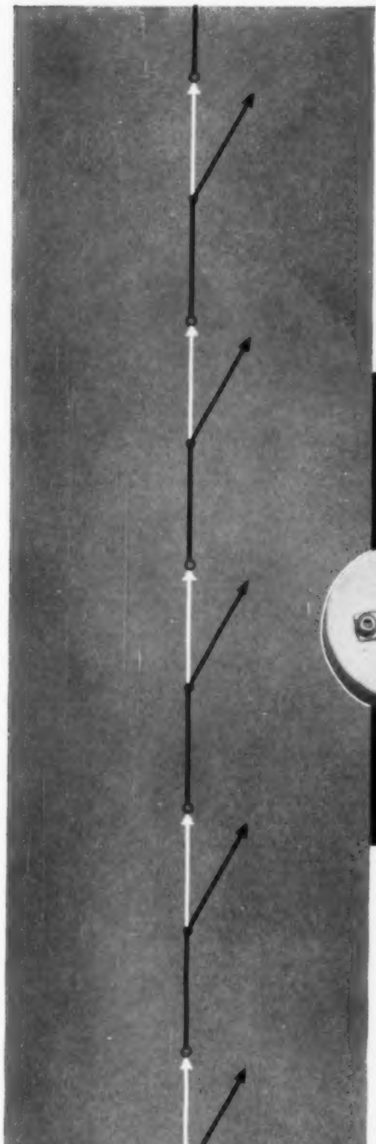

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PRICES & SUPPLY

...AT A GLANCE

Price of chlorinated polyether has dropped again. New price for Hercules Powder's Penton is $2.50 per lb for natural color, $2.60 per lb for olive drab and black. Last summer price of the material was dropped from $6 to $3.50 per lb for natural and to $3.75 per lb for olive drab and black (M/DE, Aug '59, p 19).

Price cuts on specialty alloy steels have been announced by three major producers. Universal-Cyclops Steel Corp. made cuts of about 13% on forging billets for high strength, low alloy steels that go into rocket motor cases and other missile parts. Allegheny Ludlum Steel Corp. announced price cuts on its line of low alloy steels used in high temperature applications such as jet engine parts. Details of the price cuts were not immediately available, as the steels affected are a large group of alloys that vary widely in price. Crucible Steel Co. of America announced a price cut on its Ladish D6 high strength alloy steel used in aircraft and missile parts. New price is 74¢ per lb, down 11¢ per lb.

Price of fir plywood has dropped to its lowest level in 10 years. Roseburg Lumber Co. has cut its price on 1/4-in. thick sanded fir plywood to $60 per 1000 sq ft, down $4 per 1000 sq ft. Other major plywood producers say they will not lower their prices.

Open hearth steel output could possibly be doubled as the result of a new process. It uses a combination of fuel and oxygen, and substitutes burned lime for limestone in order to hasten chemical and thermal reactions that convert various ingredients into molten steel. A 200-ton furnace charged by the new method has averaged more than 60 tons of steel per hr, compared with 30 tons per hr previously. The process, still in the experimental stage, was developed by Ford Motor Co.

Tellurium's price has been increased 50¢ per lb by American Smelting & Refining Co. Powder and slabs are now quoted at $3.50 per lb in 100-lb lots. The price increase does not apply to smaller lots of the material, according to the company.

Another price reduction for Delrin acetal resin has been announced by Du Pont. New price is 80¢ per lb in truckload quantities. Not long ago price of the material was dropped from 95¢ to 88¢ per lb (M/DE, Feb '60, p 23). The resin was put into commercial production last January.

A new supplier of polystyrene is Shell Chemical Co., 50 W. 50th St., New York 20. M. Buck, general manager of the Plastics and Resins Div., says the company has started commercial production of general purpose and high impact polystyrene in a full range of colors. Production figures were not disclosed.

Price reductions on nylon 6 molding compound have been announced by Allied Chemical Corp. and Foster D. Grant Co. Allied's new price is $1.11 per lb, down 7¢ per lb. Foster D. Grant's new price is $1.04 per lb, down 14¢ per lb.

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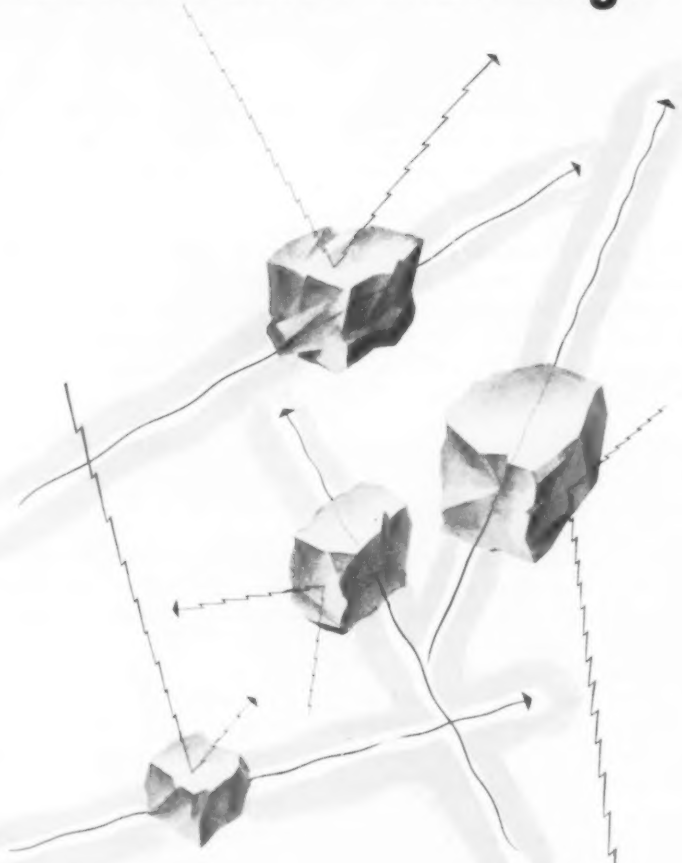

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New Materials and Processes Discussed at Design Conference

One of the key points made at the recent Design Engineering Conference was the necessity for improving present methods of joining the newer metals and alloys.

According to John S. Chyle, director of welding research for A. O. Smith Corp., ". . . space age dreams can be transformed into reality if present methods of joining new metals can be improved. As we make progress in the development of new metals such as columbium, vanadium, zirconium, hafnium, and tantalum, the problems of fabricating them by welding must also be resolved."

Mr. Chyle, speaking at the Fabrication of Materials Session at the American Society of Mechanical Engineers' annual Design Engineering Conference, pointed out that there are several new processes that may answer some of the problems. Two of the processes described were developed by the Russians: friction welding and electroslag welding. Other processes discussed were electron beam welding and brazing of aircraft structures.

Explosive forming

Also covered during the Fabrication Session was the shaping of metal parts by explosion. According to papers by Vasil Philipchuk, manager of the special projects dept., American Potash and Chemical Corp., and R. A. Cooley, vice president, Propellex Chemical Div., Chromalloy Corp., this forming method is solving many fabrication problems in the design of parts ranging from a few grams to over two tons. It has been successfully used on such metals as tantalum, uranium, beryllium, columbium, molybdenum and zircaloy, as well as the familiar steels, magnesium, copper and nickel alloys. It can also be used to make welds. Thus far, rocket nozzles, missile domes, nose cones, aircraft parts and rocket motor cases have been fabricated by this process.

Reinforced plastics

An interesting paper covered the use of glass-reinforced plastics and other nonmetallic composite materials for missile cones, rocket nozzles and other parts of space craft. The paper, by William E. Dirkes, Chief of the Plastics Branch, Materials Laboratory, Wright-Patterson Air Force Base, pointed out that these materials can provide the strength, weight and pliability that metals lack. In addition, they can be tailored to specific needs. On the other hand, ". . . this same variability, uncontrolled, can be disastrous. . . . To avoid failure of the materials in use," Mr. Dirkes said, "minimum standards for each part of the material must be determined and met. . . . This control is essential for any critical application, for there is no satisfactory nondestructive test for quality of these laminate materials."

High strength steel

Rounding out the materials sessions was a paper on "Some Considerations in the Use of High Strength Steels." The paper, by A. M. Hall, division chief, Battelle Memorial Inst., discussed properties, available forms and applications of low alloy hardenable steels, chromium hot work die steels, martensitic stainless steels, precipitation hardenable steels and cold rolled stainless steels.

Successful show

The 1960 Design Engineering Show, sponsored by Clapp and Poliak, Inc., concentrated on products of the future. Over 400 leading companies exhibited such things as metallic and nonmetallic materials; finishes and coatings; forms and shapes; fasteners and adhesives; mechanical, electrical, electronic and hydraulic components; and research, testing and other services for product development.

Powder Metallurgists Cover Testing, Dispersion Hardening

The increasing importance of developing effective nondestructive testing techniques for metal powder parts was clearly evident at the 16th annual Technical Meeting and Exhibit of the Metal Powder Industries Federation.

(continued on p 23)

Three key papers on nondestructive testing opened the two-day meeting. The first covered electronic resonance testing of cast and sintered small arms components. The second presented the hypothesis that a linear relationship exists between strength and hardness in cemented carbide. If the theory can be proven in actual tests, computation could replace destructive tests of these expensive products. The third testing paper covered density variation detection in powder metallurgy parts by use of eddy currents.

One of the highlights of the meeting was the paper given by Dr. N. J. Grant of Massachusetts Institute of Technology on powder metallurgy fundamentals. Dr. Grant discussed advancements made in dispersion strengthening by powder metallurgy.

Other subjects of interest covered at the meeting were: application engineering for powder metallurgy, stainless steel powder metallurgy, superalloy powder metallurgy, nickel-coated composite powders, and tests on low temperature impact strength of sintered steels. Also, three talks were given on testing, evaluation and use of magnetic powder.

PMPMA joins MPIF

One of the most important features of the meeting was the announcement that the Powder Metallurgy Parts Manufacturers Assn. has united with MPIF to become the sixth of the Federation's autonomous trade associations.

Founded in 1957, PMPMA was an independent trade association representing contract manufacturers of powder metallurgy mechanical and structural components and self-lubricating bearings.

Up to now, this group has been somewhat divided: part of the members belonged to MPIF and part had their own separate organization. The members of both groups now constitute a new Powder Metallurgy Parts Manfacturers Assn. operating within the framework of MPIF.

The joining of forces means that the Association now represents not only the majority of companies engaged in the contract manufacture of powder metallurgy parts, but also by far the greatest volume of production.

Organo-Metalloids Covered at Symposium

A special two-day symposium, designed to stimulate research on new materials for extreme conditions of temperature, pressure, speed, corrosion and radiation, was recently held at Armstrong Cork Co.'s Research and Development Center, Lancaster, Pa.

The new materials, especially the organo-metalloid polymers, are expected to solve many future materials problems, particularly as insulation or as component parts of advanced machinery.

Some of the subjects covered: coordination polymers, synthesis of phosphorus and silicon-containing polymers by a cyclic mechanism, polymers containing tin, properties of boron-phosphorus polymers, and thermal stability in polymer materials.

ASM Discusses Space Materials

The essential role of materials in space flight was the subject of the recent two-day technical meeting conducted by the Cincinnati, Dayton and Columbus Chapters of the American Society for Metals.

The meeting was divided into four sessions. The first, "Space Flight—Its Unique Demands on Materials," introduced and explained the critical problem areas. The second session, "Materials for Space Vehicle Launching Systems," covered the materials used in all types of rocket engines, including experimental nuclear rockets now under development. The third session, "Materials for Use in Outer Space," discussed testing of materials under simulated space environments and the unique materials required for generating power in outer space and propelling space ships.

The final session, "Materials for Atmospheric Re-entry," considered materials to withstand the meteoric heating encountered on re-entering the earth's atmosphere, especially those used in the X15 aircraft and the Project Mercury manned re-entry capsule.

Some of the specific topics discussed were: how metals behave in the intense vacuum of outer space, how materials behave in the white-hot nose cones of missiles and manned space capsules, and materials for the giant rocket engines required for launching space vehicles.

News of Societies

Copper & Brass Research Assn. has elected the following officers: president—G. P. Bakken, Chase Brass & Copper Co.; senior vice president — E. P. Dunlaevy, Phelps Dodge Copper Products Corp.; treasurer—F. L. Riggin, Sr., Mueller Brass Co.; managing director—T. E. Veltfort; and secretary—Carl H. Pihl.

American Welding Society has elected R. D. Thomas, Jr., Arcos Corp., 1960-1961 president. The Society has also honored the following men: B. E. Rossi, editor, *The Welding Journal*, has received the Samuel Wylie Miller National Award; and Dr. Robert D. Stout, Lehigh University, has been named this year's Adams Lecturer.

Coming Meetings on p 25 ⟶

News OF INDUSTRY

Coming Meetings

NATIONAL ASSN. OF METAL FINISHERS, annual meeting. Los Angeles. July 22-24.

AMERICAN ELECTROPLATERS' SOCIETY, annual meeting. Los Angeles. July 24-28.

4TH NATIONAL HEAT TRANSFER CONFERENCE AND EXHIBIT, American Institute of Chemical Engineers and American Society of Mechanical Engineers. Buffalo, N. Y. Aug 14-17.

SOCIETY OF AUTOMOTIVE ENGINEERS, INC., national West Coast meeting. San Francisco. Aug 16-19.

PRODUCTION ENGINEERING SHOW. Chicago. Sept. 6-16.

MACHINE TOOL EXPOSITION, National Machine Tool Builders' Assn. Chicago. Sept 6-16.

ELECTRONIC INDUSTRIES ASSN., fall meeting. French Lick, Ind. Sept. 13-16.

AMERICAN DIE CASTING INSTITUTE, annual meeting. Chicago. Sept 14-15.

STEEL FOUNDERS' SOCIETY OF AMERICA, 58th fall meeting. Hot Springs, Va. Sept 18-20.

POWER CONFERENCE, American Society of Mechanical Engineers and American Institute of Electrical Engineers. Philadelphia. Sept 21-23.

NATIONAL FOUNDRY ASSN., annual meeting. Chicago. Sept 22-23.

AMERICAN WELDING SOCIETY, INC., national fall meeting. Pittsburgh. Sept 26-29.

15TH ANNUAL INSTRUMENT-AUTOMATION CONFERENCE AND EXHIBIT, Instrument Society of America. New York City. Sept 26-30.

RUBBER AND PLASTICS CONFERENCE, American Society of Mechanical Engineers. Erie, Pa. Oct 9-12.

ELECTROCHEMICAL SOCIETY, fall meeting. Houston, Tex. Oct 9-13.

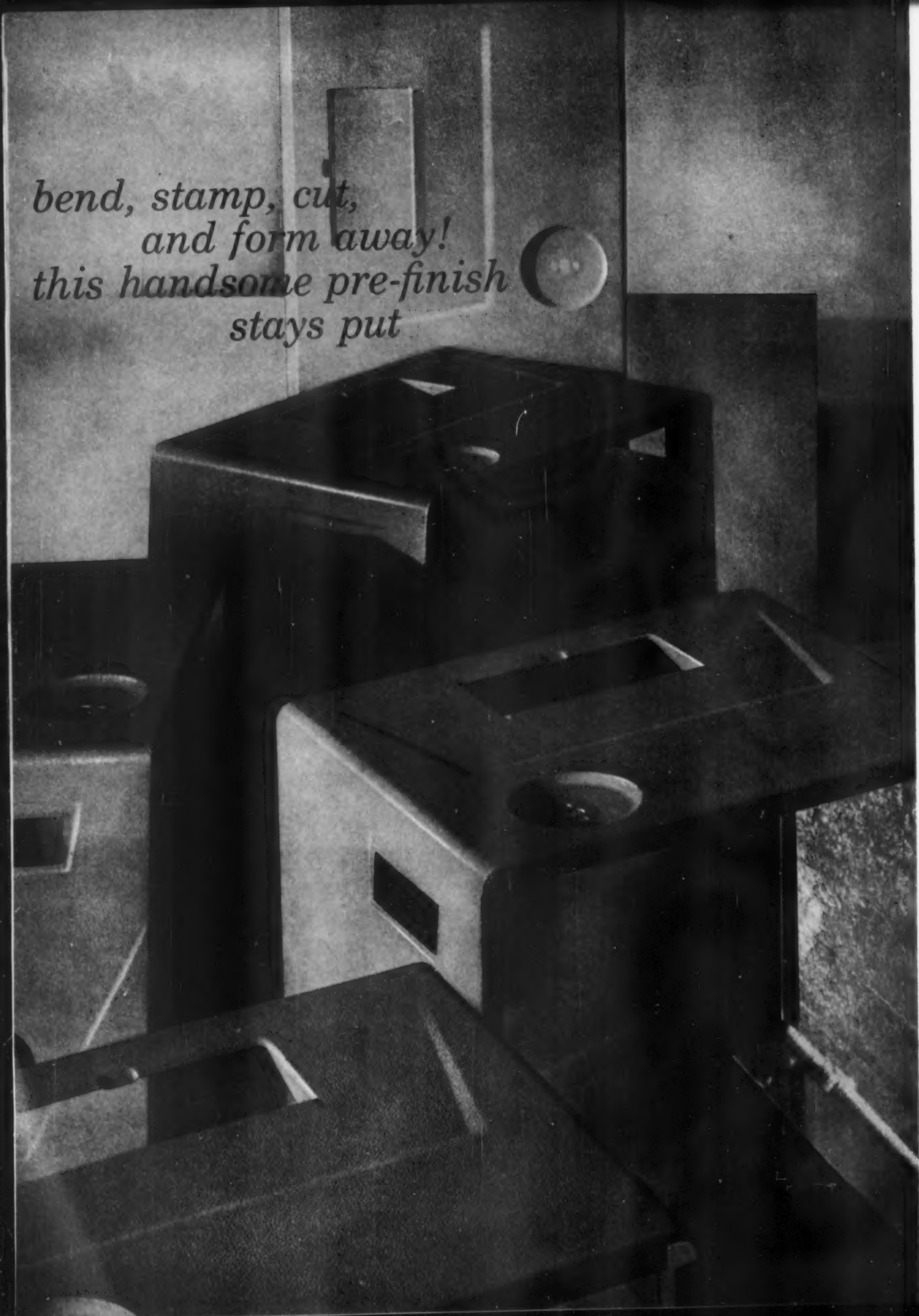
NATIONAL ELECTRONICS CONFERENCE, INC., 16th annual meeting. Chicago. Oct 10-12.

PRESSED METAL INSTITUTE, annual meeting. Shawnee-on-the-Delaware, Pa. Oct 10-14.

SOCIETY OF THE PLASTICS INDUSTRY, INC., 16th annual New England Section conference. Wentworth-by-the-Sea, Portsmouth, N. H. Oct 13-14.

NON-FERROUS FOUNDERS' SOCIETY, annual meeting. Asheville, N. C. Oct 13-15.

For more information, turn to Reader Service card, circle No. 446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	224E-75	"Tuf-Stuf" Aluminum Bronze	BRINELL 1000 KG load 175
	224C	"Tuf-Stuf" Aluminum Bronze	BRINELL 1000 KG load 185
	224H	"Tuf-Stuf" Aluminum Bronze	BRINELL 1000 KG load 200
	224K	"Tuf-Stuf" Nickel Aluminum Bronze	BRINELL 3000 KG load 250
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	601	Forgeable Bearing Alloy	ROCKWELL-B 87
	602	Leaded Forgeable Bearing Alloy	ROCKWELL-B 87
	604	High Leaded Forgeable Bearing Alloy	ROCKWELL-B 86
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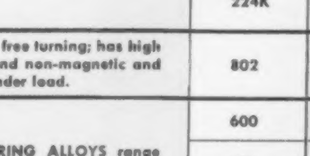

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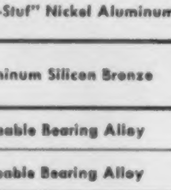

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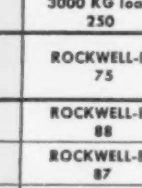

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70,000	90,000	30
65,000	105,000	20
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60,000	90,000	25
55,000	78,000	35
65,000	85,000	65
55,000	75,000	80
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55,000	78,000	25
68,000	115,000	35
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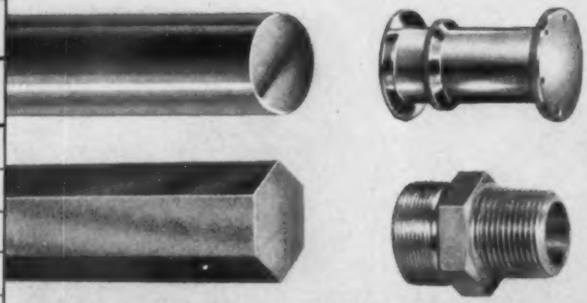

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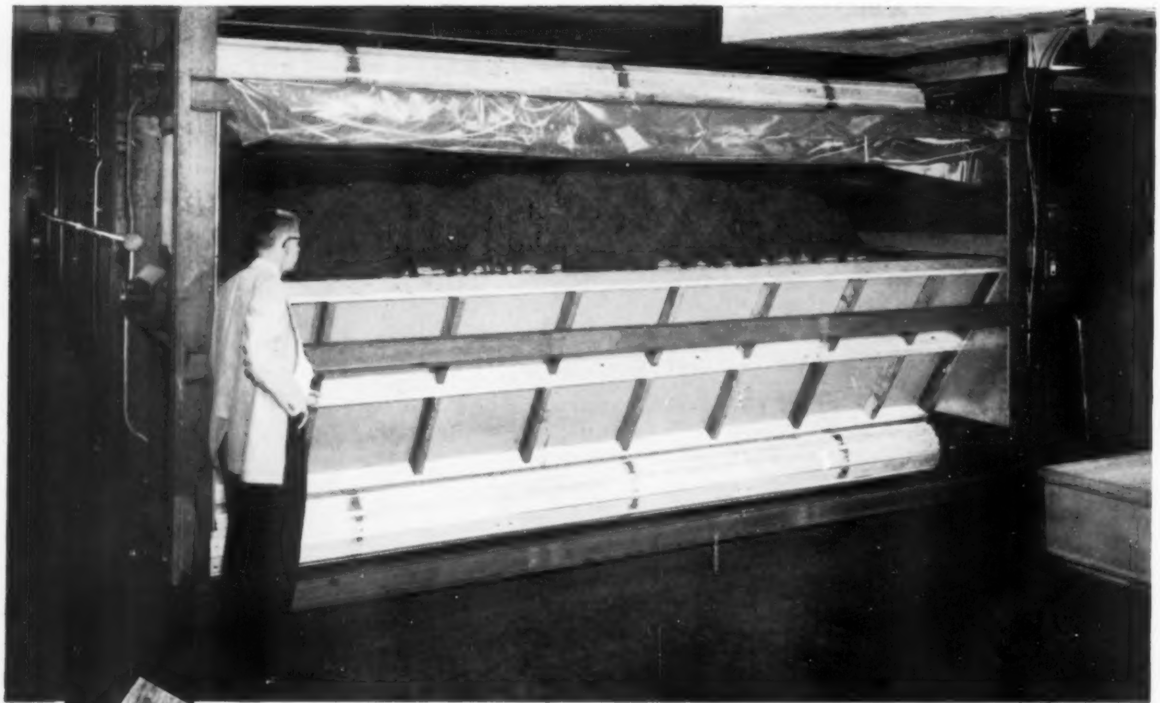

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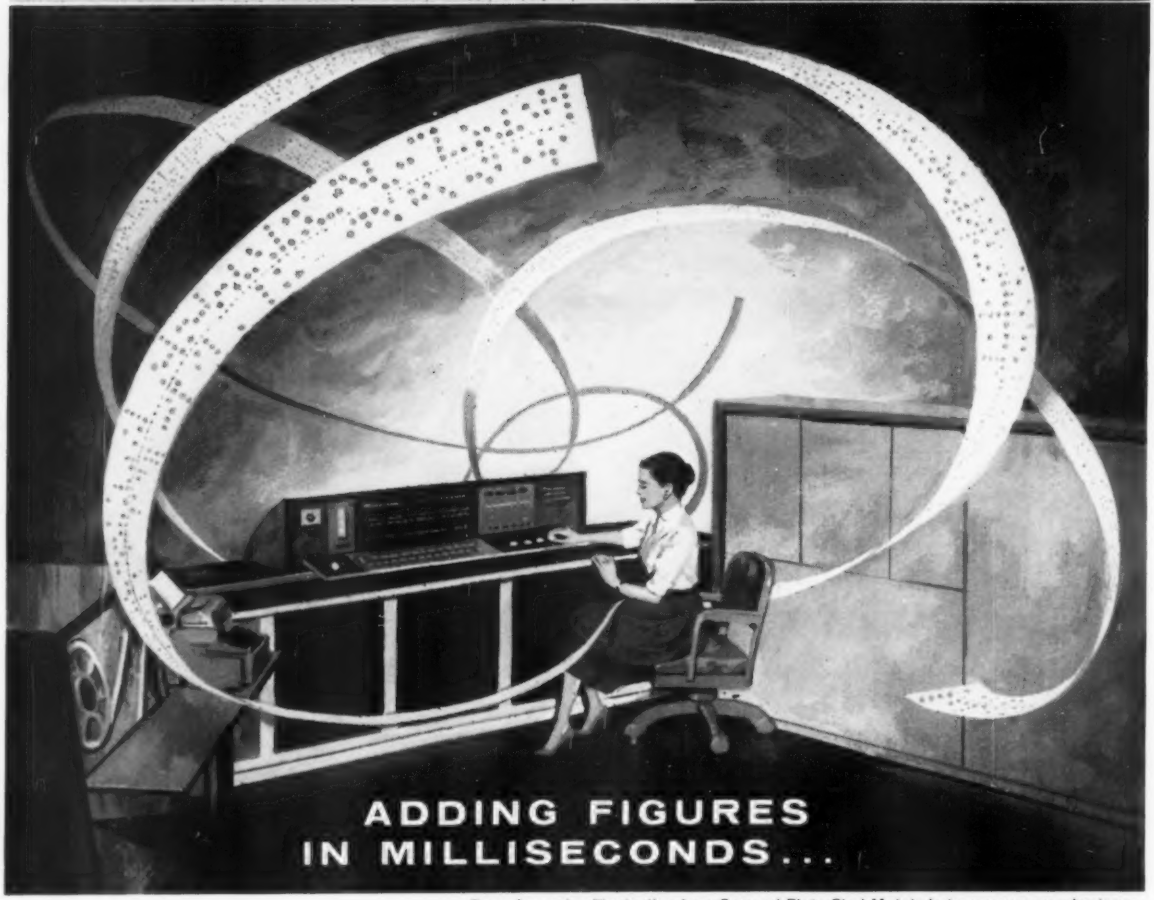

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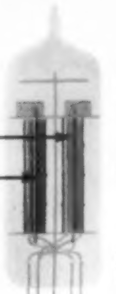

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Oriented Electrical Steels. Armco Steel Corp., 4159 Curtis St., Middletown, Ohio, 64 pp, illus. Classification; advantages; physical, mechanical and magnetic properties; surface preparation; and other technical data on a line of oriented electrical steels. Write on company letterhead directly to Armco.

Wire Parts, Small Stampings. Art Wire & Stamping Co., 4 pp, illus. Shows a variety of wire parts and small metal stampings in both ferrous and nonferrous metals. **46**

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Lightness, ease of fabrication and other features of magnesium contribute to improved designs for many products—from airplanes and missiles to luggage . . . from industrial machinery to cameras. Now, new developments by Dow provide greater design flexibility than ever before—in fabricated components you require, in materials and processes to facilitate your plant's operations.

New sheet is bent without heated dies.

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Especially useful for aircraft and missile designers, this close tolerance sheet is also suggested for use in air-transported equipment or wherever minimum weight is critical.

COMPARISON OF TOLERANCES

48-inch-wide sheet

Gauge	Close Tolerances	Standard Tolerances
.032"	±.0013"	±.0025"
.040	±.0015*	±.003
.050	±.002	±.004
.063	±.002	±.004
.071	±.002	±.004
.080	±.002	±.004
.090	±.002	±.004
.100	±.0025	±.005
.125	±.0025	±.005
.160	±.004	±.008
.190	±.005	±.010

*For HM21A-T8 .040" close tolerance is ±.002".

NEW SPECIAL BEND SHEET ELIMINATES HEATED DIES

Critical bends can now be easily formed at room temperature – *without heated dies*—using Dow's new AZ31B-O Special Bend Sheet. Without cracking, it bends through an angle of 90° around a mandrel radius as small as two times the nominal sheet thickness. Among many suggested applications are housings for electronics equipment, truck cabs, shipping containers, plus such military uses as maintenance and personnel shelters and housings for ground support equipment.

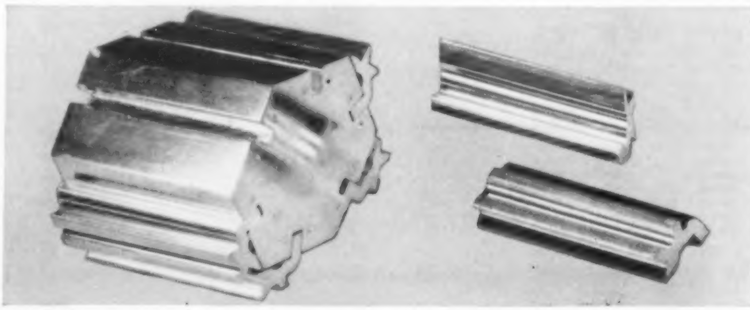
BEND FACTORS		
Nominal thickness	Longitudinal bend factor	Transverse bend factor
0.040"–0.100"	2.0	2.5
0.101"–0.190"	2.5	3.0

Tensile yield strength meets Federal Specifications AA-M-44.

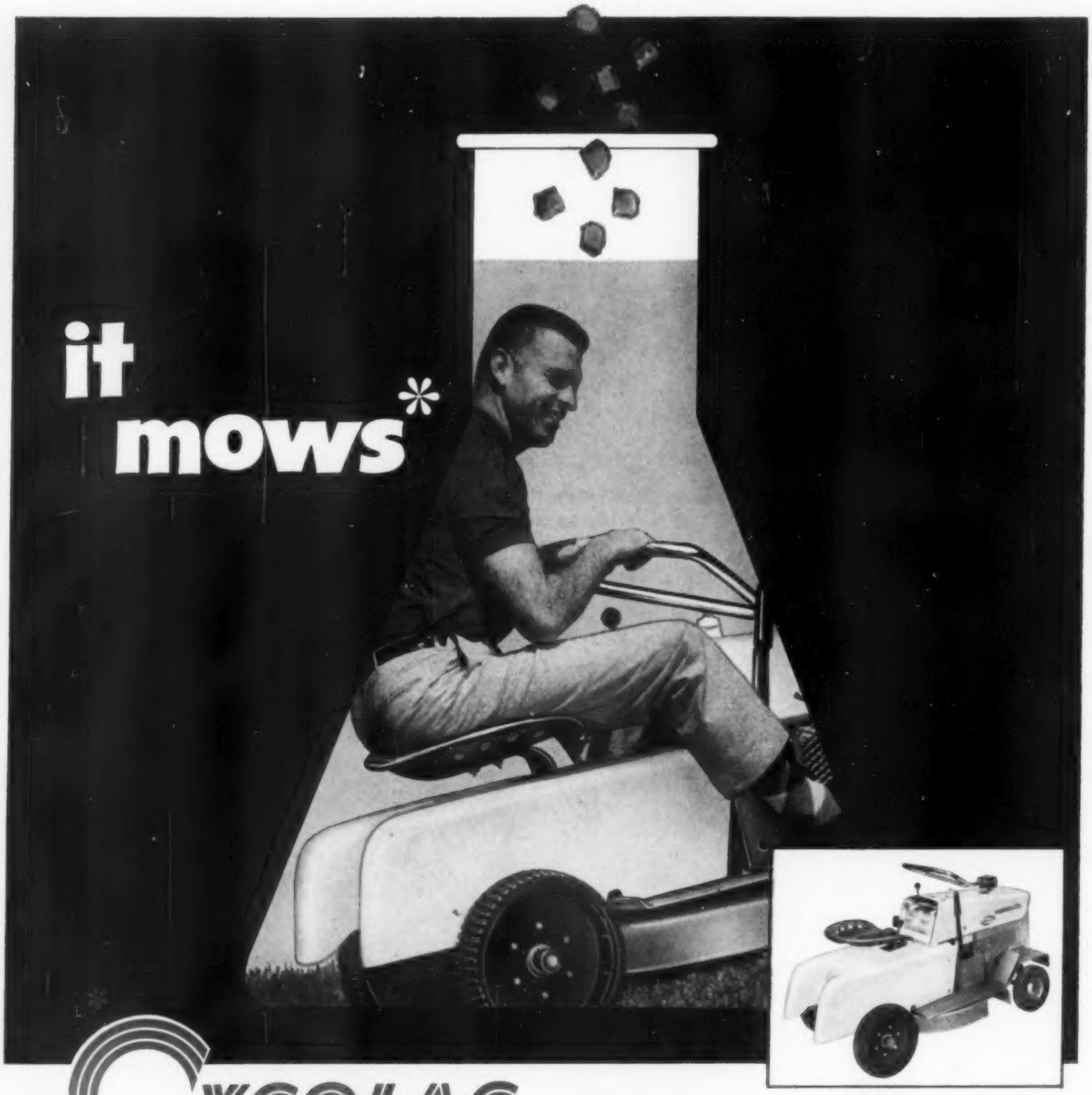
PRECISION MAGNESIUM EXTRUSIONS CUT MACHINING COSTS

Dow precision magnesium extrusions provide exact-tolerance finished or semi-finished components and eliminate many costly multiple machining operations. Exacting tolerances are even possible with sharp V's, deep notches, thin slots, sharp serrations, as well as precision diameter tubing. And with precision extrusions, cost of materials is also frequently less because high-property alloys to withstand extensive machining are not needed.

Applications include bearing blocks, impact extrusion stock, parts for business machines, printing furniture, screw machine stock, shaft shear keys, spacers and airfoil configurations.



Exact-tolerance extrusions cut machining costs.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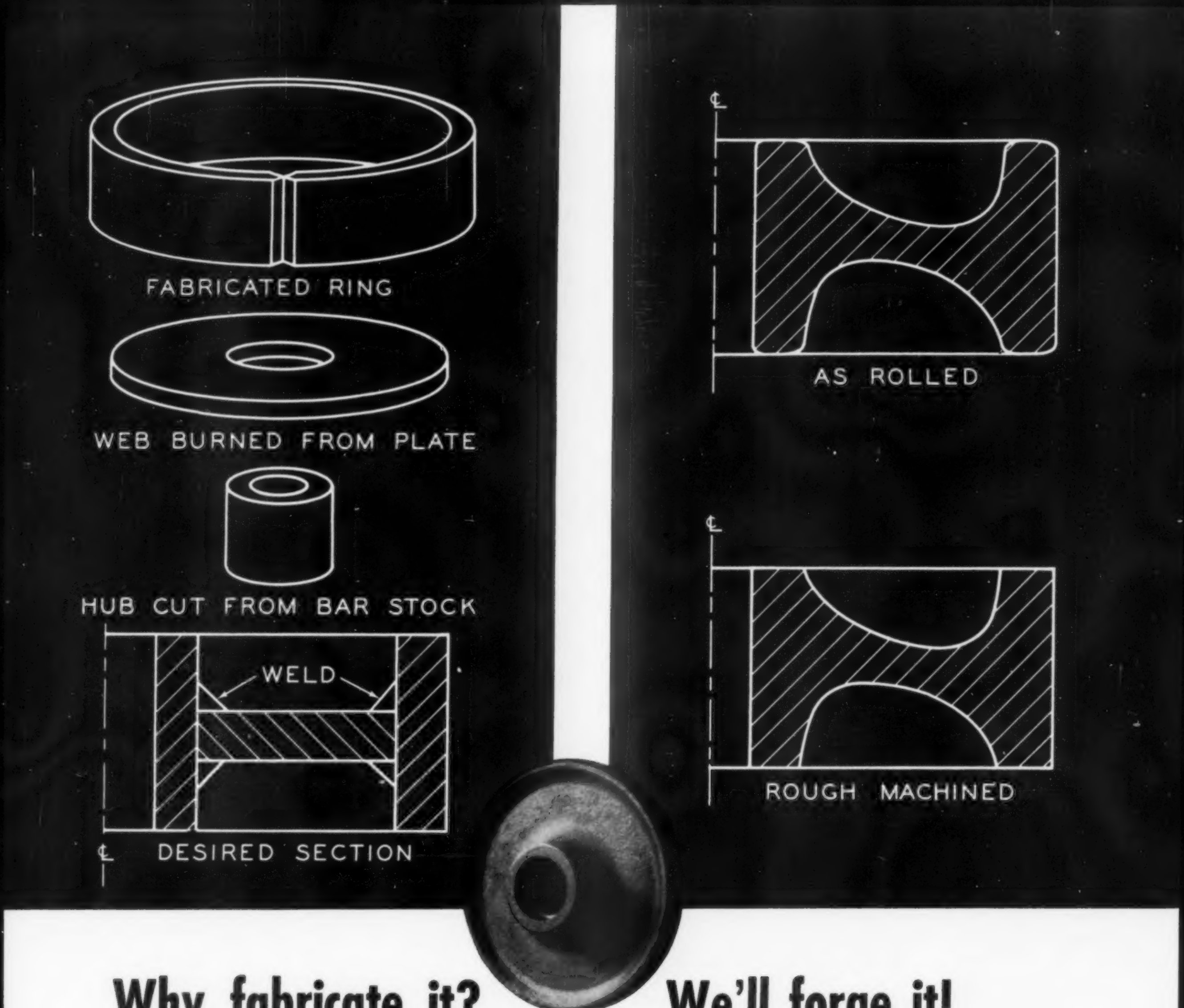
mows*



Why fabricate it?

(and pay for waste metal, assembly time, welding?)

We'll forge it!

(and cut your costs: less metal, no assembly or welding)

Bethlehem Circular Forgings come ready for finish machining. Unlike a weldment, there's no fabricating to be done. No assembling. No welding. You save the high cost of all those operations—and the cost of the metal those operations waste.

Cost? Thanks to our Slick Mill (the only one of its kind in the country), the cost of Bethlehem Circular Forgings is low. Even if new tooling is required, orders of 20 or more pieces are economical (dies can be changed in just 15 minutes). Our mill forges and rolls an impression-die forging in about one minute. Because contact time between die and work is so brief, and because there's no impacting, low-cost dies can be used.

There you have it. One, important fabrication savings. Two, low initial price. That's why forged circular products consistently cost less than weldments.

Bethlehem Circular Forgings are available in carbon, alloy, or stainless steels, and some heat-resistant grades. 10 to 48-in. OD. 100 to 2,000 lb. As-rolled or rough-machined to specifications. For full details, call or write the Bethlehem sales office nearest you.

BETHLEHEM STEEL COMPANY, BETHLEHEM, PA.
Export Distributor: Bethlehem Steel Export Corporation

BETHLEHEM STEEL

BETHLEHEM STEEL

For more information, turn to Reader Service card, circle No. 382

Closeup of coated aluminum "clapboard" sheathing joint designed to permit expansion and contraction of house siding. Plastic-based coating stays intact around intricate bends.

OUTDOORS—A DURABLE VINYL-BASED PAINT TO PRE-COAT HOUSE SIDING BEFORE FORMING

Baked onto the metal before forming, vinyl-based coatings stand up under the strain of shaping and years of service as well. On house siding, weather resistance is a big factor, and the adjoining photograph shows how the aluminum clapboard on a Milwaukee home looked after nine years without refinishing. The coating is still intact.

Shakes as well as clapboards are being formed from this pre-coated metal. On both types, the vinyl-based finish holds fast, with no cracking, chipping, or peeling during shaping, assembly and service. Both primer and topcoat can be applied by roller, brush, or spray. Baking turns the topcoat into a tough, flexible, weather-resistant finish that looks good as new for years with only an occasional washing.

One company pre-coats and bakes the finish on aluminum sheathing which is then formed over an insulation board made of wood fibers, asphalt-treated for weather and water resistance. Another manufacturer designed a special interlocking joint (closeup) that permits expansion and contraction with temperature changes to prevent buckling. What vinyl-based coatings are doing for building materials, they will do for many other products that can be made from pre-coated metal sheets formed at a saving.

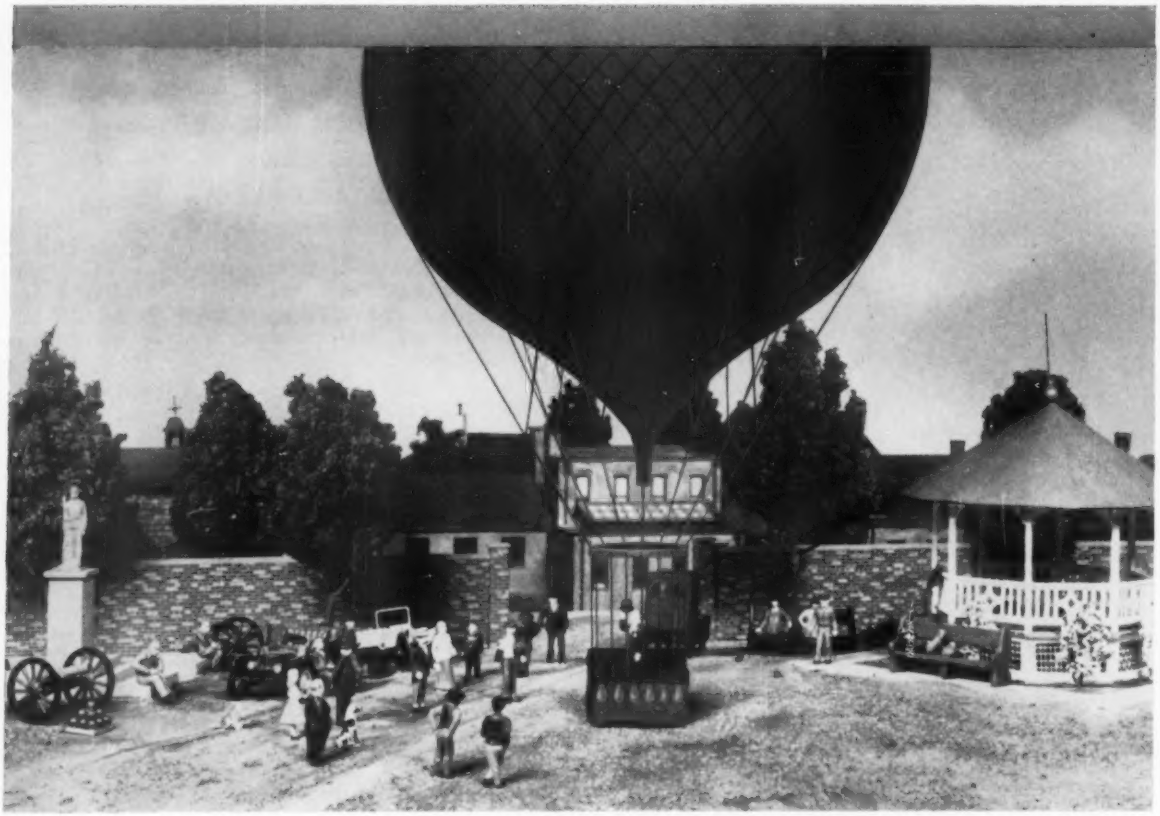
LET PLASTIC-BASED COATINGS

ARTIFICIAL WINDSTORM—OTHER COATINGS BLEW AWAY, BUT PHENOLICS STUCK TO THIS WIND TUNNEL

Before phenolic-based coatings were tried, the paint inside this 8-foot transonic wind tunnel would literally blow off the surface. Nuts and bolts occasionally loosened from models struck the sides and scored the paint. Ordinary paints didn't last long under these conditions.

But a coating based on BAKELITE Brand phenolics was still adhering firmly, in good shape, after two years. Along with extreme durability, its smooth glossy surface demonstrated far greater freedom from friction and resistance to scoring.

Plastics have brought a new set of performance standards to the coatings field. They fit into the new service-environments your designs have to meet, and deserve thorough investigation when you're planning a new approach.

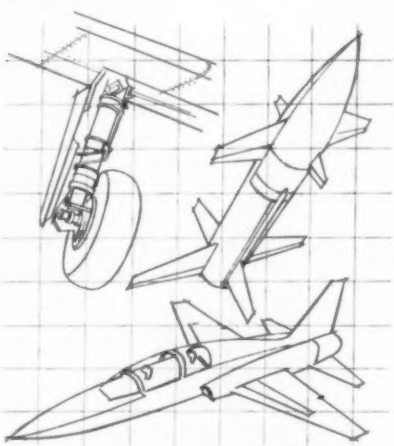


Are you up in the air over tubing sources?

If you have ballooning production problems, consider these important facts. OSTUCO Tubing is always the exact tubing you need for your product because OSTUCO Tubing is CUSTOM MADE for your product. Your order is manufactured to your own specifications to produce steel tubing especially for your application — the precise grade, analysis, size, shape, special anneal and tolerances best suited to your needs.

Ohio Seamless Tube produces both seamless and electric welded steel tubing — is prepared to form many finished or semi-finished tubular parts to your designs.

To get the most from your next steel tubing order, use Custom Made OSTUCO Tubing. Contact your nearest Ohio Seamless representative, or send part drawings to the plant at Shelby, Ohio — Birthplace of the Seamless Steel Tube Industry in America.



Model illustrated built to 3.5 mm scale.

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OHIO SEAMLESS TUBE

Division of Copperweld Steel Company • SHELBY, OHIO

Seamless and Electric Resistance Welded Steel Tubing • Fabricating and Forging

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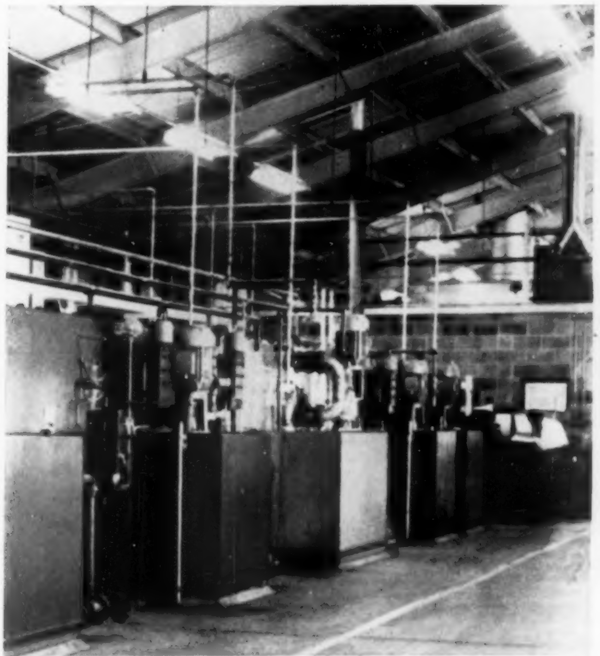
CANADA: Railway & Power Engr. Corp., Ltd. • EXPORT: Copperweld Steel International Company, 225 Broadway, New York 7, New York

For more information, turn to Reader Service card, circle No. 412

CONTROL CENTER

on high production aluminum strip lines



This Bonderite installation at Kaiser Aluminum's Ravenswood Works, Ravenswood, West Virginia, handles aluminum strip up to 66 inches wide. Tandem Parker Reactifiers remove contaminants from the Bonderite solution as they are formed, keeping coating quality at a constant high level.

The Parker Reactifier, "Quality Control Center" of Bonderite for aluminum on high production strip lines. Bonderite enters at "A"; resin "B" removes impurities by cation exchange action; purified solution is returned at "C." Regeneration of the unit is accomplished by circulation of acid from tank "D" to cleanse resin of accumulated impurities.

turned to maintain the coating bath at top efficiency.

Proven by years of use

One Parker Reactifier has been in continuous use for over three years on a Bonderite high production aluminum strip line. In all that time there has been no deterioration of the cation resin, no sludge build-up, and no reason to discard the bath. This manufacturer now is installing a second strip line for Bonderizing aluminum with another Parker Reactifier for quality control.

In the comparatively short time Parker Reactifiers have been available, the largest manufacturing and fabricating plants have installed 30 of them to assure high quality coatings on aluminum.

You'll be proud of the finish on your product when you use Bonderite before painting. It improves paint life five to ten times. Call in the Parker man today!

Bonderites for aluminum meet MIL-C-5541 specifications.

Parker Rust Proof Company
2173 E. MILWAUKEE, DETROIT 11, MICHIGAN

Since 1914— leader in the field

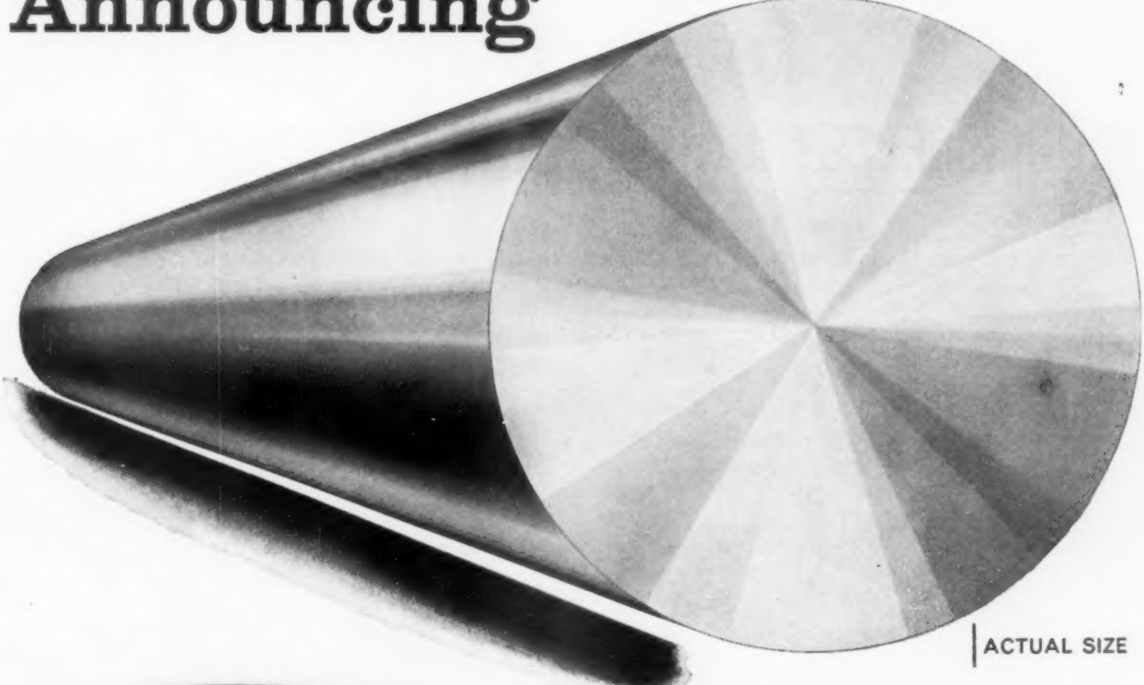
BONDERITE corrosion resistant paint base • BONDERITE and BONDERLUBE aids in cold forming of metals • PARCO COMPOUND rust resistant • PARCO LUBRITE—wear resistant for friction surfaces • TROPICAL—heavy duty maintenance paints since 1883

Since 1914—Leader in the field

*Bonderite, Bonderized, Bonderlube, Parco, Parco Lubrite—Reg. U.S. Pat. Off.

For more information, turn to Reader Service card, circle No. 333

Announcing



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Same high strength as smaller diameters . . . 100,000 psi yield.

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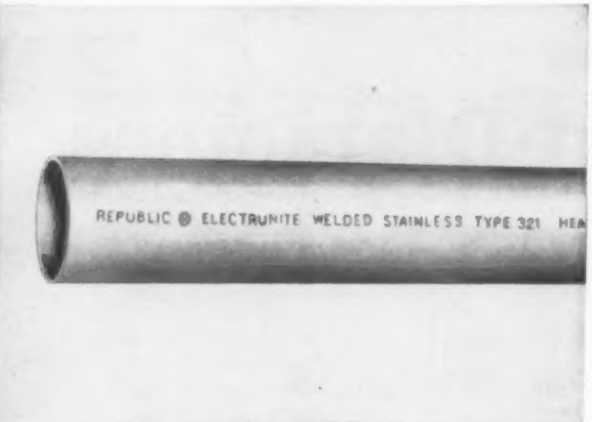
Grumman Aircraft Engineering...
SAVES TAXPAYER DOLLARS WITH REPUBLIC ELECTRUNITE STAINLESS STEEL TUBING

Grumman Aircraft Engineering Corporation has substantially reduced production costs of the exhaust system used in the Grumman S2F Tracker, through the use of Republic ELECTRUNITE Stainless Steel Tubing.

Since using ELECTRUNITE, Grumman has reduced scrap loss by 50%. Fabrication time is 30% less, with further savings through longer tool wear.

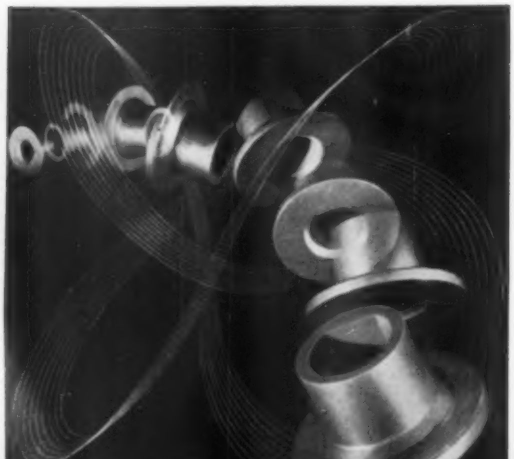
ELECTRUNITE® Stainless Steel and Carbon Steel Tubing is available in a wide range of sizes, gages, wall thicknesses, to meet practically any national security, manufacturing, fabricating, and pressure tubing application. Call your Republic representative for complete information and specifications. Or, write direct.

Republic ELECTRUNITE Stainless Steel Tubing, Type 321, is used in the exhaust system of the Grumman S2F Tracker, saving taxpayer dollars. ELECTRUNITE can save money for you, too.

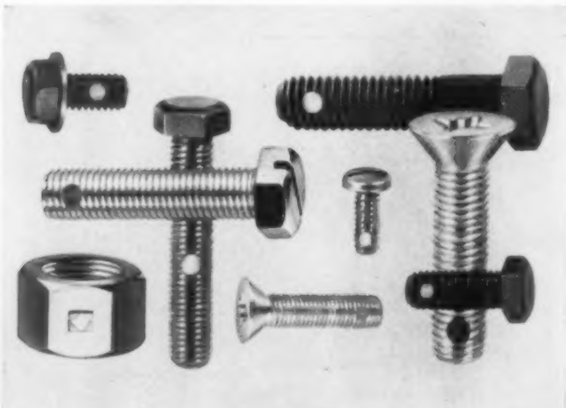


Further savings are realized through Republic's Steel and Tubes Division manufacturing facilities of bending, forming, welding operations. Write for information.

REPUBLIC HS6460 HIGH STRENGTH POWDER can be used to produce comparable strength structural parts at lower manufacturing costs than obtainable with copper infiltration. Additional production economies can be achieved because fewer operations will be required to obtain high density, higher strength parts. HS6460 is capable of a minimum tensile strength of 60,000 psi at 6.4 density —100,000 psi after heat treatment. Write today.



REPUBLIC NYLOK® SELF-LOCKING FASTENERS provide a single-unit answer to vibration, shock, and tension. A permanent nylon insert forces mating threads together for maximum holding power in any postion. The relatively inert nylon resists age and moisture; its natural resiliency permits easy adjustment and repeated use. Republic NYLOK Fasteners are non-galling and require no lubricants. Send coupon for descriptive literature; specify bolts or nuts, or both. Use the convenient coupon, below.



GRUMMAN S2F TRACKER—first airplane specifically designed to detect, identify, track, and destroy enemy submarines. The Tracker utilizes radar, sonobouys, and Magnetic Airborne Detector gear to pinpoint the enemy, then chooses either torpedo, depth charges, or rockets to effect the kill.

REPUBLIC CAN DO IT FOR YOU with complete sheet steel fabrication facilities. Contract manufacturing is a full-time operation at Republic's Berger Division. Engineers work with you in developing your product and in solving manufacturing, assembly, and delivery problems. Well rounded stock of tools, dies, and a complete machine shop. Modern production lines for shearing, punching, forming, painting and assembly. To learn more about Republic-Berger contract facilities, call your Republic representative, or write today.

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Please send more information on the following products:

☐ Republic ELECTRUNITE® Stainless Steel Tubing ☐ Carbon
☐ Republic Steel and Tubes Division Manufacturing Facilities
☐ Republic HS6460 High Strength Powder
☐ NYLOK Fasteners ☐ Bolts ☐ Nuts ☐ Both
☐ Republic Berger Division Contract Facilities

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Firm________________________

Address______________________

City____________ Zone____ State______

For more information, circle No. 366

DEPENDABILITY, ECONOMY and STRENGTH are distinguishing characteristics of these sintered metal automotive transmission parts by Delco Moraine. Vital components such as these are typical results of close collaboration between Delco Moraine and its customers—an effective liaison that operates from idea through design and development. They also attest to Delco Moraine's equally important capabilities for making deliveries in quantity and on time!

DELCO MORAINE

DEPENDABLY MADE *parts for industrial progress • Division of General Motors, Dayton, Ohio*

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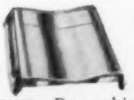
For more information, circle No. 421 ➤

Swedlow specializes in heat protection!

Silicones
Phenolics
Epoxies
Reflective coatings
Sheet materials
Molded parts
Flexible flame-resistant coatings

Swedlow's aluminum-metallized heat reflective laminates

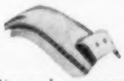


1650°F

MINIMUM WEIGHT • MINIMUM BULK—By combining the principles of highly efficient reflectivity of aluminum-metallized surfaces with the low thermal conductivity of glass fabric reinforced plastic laminates, Swedlow's "—101" metallized coatings offer protection up to 1650°F. The metallic coating protects the base laminate from thermal degradation.

APPLICATIONS—In flat sheets, or molded into complex contours, these materials are suggested as highly efficient heat blankets for compartment insulation, valve protection, exhaust heat damping, and other applications where there is prolonged high temperature exposure.

Swedlow's silicone plastic laminates



650°F

Swedlow's X5G-138 and X5G-176 silicone base materials are available as flat sheeting or molded parts and offer protection up to 650°F.

Swedlow's X5G-138 provides maximum strength per unit of thickness and weight and is recommended for applications requiring flat sheets or simple contoured molded parts.

The X5G-176 laminate has slightly lower physical properties than X5G-138 but is recommended for applications requiring complex contours.

APPLICATIONS—Missile nose cones, exit cones, fins, stabilizers, adapter rings, closure rings, and similar uses. Applications in airstreams at missile speeds are possible.

Dyna-Therm 65—flexible flame-resistant coating

6000°F

A "major breakthrough"—insulation which can be applied easily in the field for protection of launching equipment from rocket flame and blast. It affords major dollar savings by protecting expensive cables and equipment through successive firings. It promises greatly reduced pad refurbishment time with resultant faster refire capability. It may be sprayed or applied with ordinary paint brush. Cures quickly at ambient temperatures. Intumesces under hot flame to develop full insulating capability, but remains flexible. Charred surface can be scraped away leaving undersurface ready for recoating. Field test indicates serviceability up to 6000°F.

APPLICATIONS—Neoprene cables, electrical connectors, metal and plastic instrumentation housings, piping and general structure, including blast deflectors. Flight applications as well as ground support installations.

600°F

Swedlow's high temperature phenolic plastic laminates

STABLE PHYSICAL PROPERTIES UNDER HIGH TEMPERATURES—Swedlow's X4G-116 is a high-temperature phenolic laminate that offers unusual physical stability at high temperatures up to 600°F. It is available in flat sheets, and can be molded to complex contours.

APPLICATIONS—Fins, stabilizers, missile nose cones, adapter rings, closure rings, and similar applications. May be used in airstreams at missile speeds.

450°F

Swedlow's epoxy-plastic laminate

Swedlow's X6G-141 epoxy-plastic laminate gives the user an electrical insulating material resistant to fracture and warpage in installation, with characteristics of very low moisture absorption and high physical strengths over a prolonged temperature gradient. Approved under MIL-P-18177. Conforms to NEMA standards for type G-3 materials.

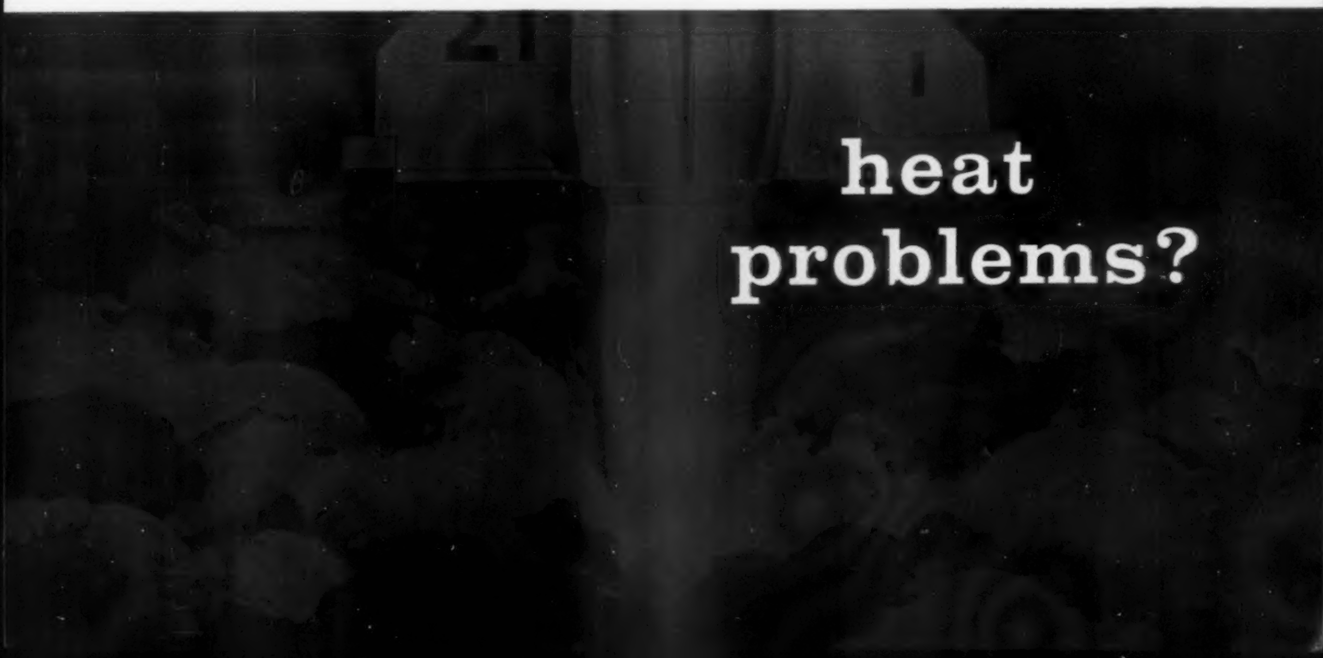
APPLICATIONS—Air conditioning and heat distribution ducts. Winding barriers and ducting in transformers. Sheeting for circuitry installations. Dielectric capacitors for condensers. Terminal board and strip applications in electronic equipment. Coil spacers and relay bases in magnetic devices. Mounting plates, contact spacers and shielding for control devices.

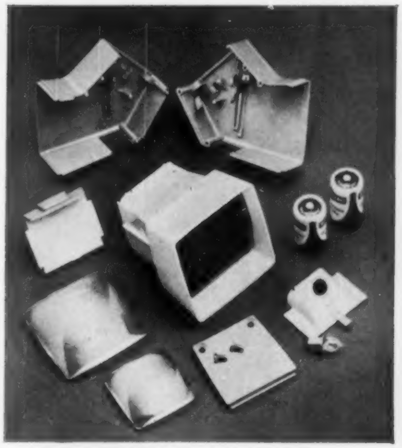
Temperatures shown may be raised appreciably for short periods.

Swedlow provides the insight to solve challenging problems of design and producibility of advanced materials—in laminates, complex shapes, difficult parts.
Write for full information, Dept. 18

Swedlow

SWEDLOW Inc.
LOS ANGELES 22, CALIFORNIA
YOUNGSTOWN 9, OHIO

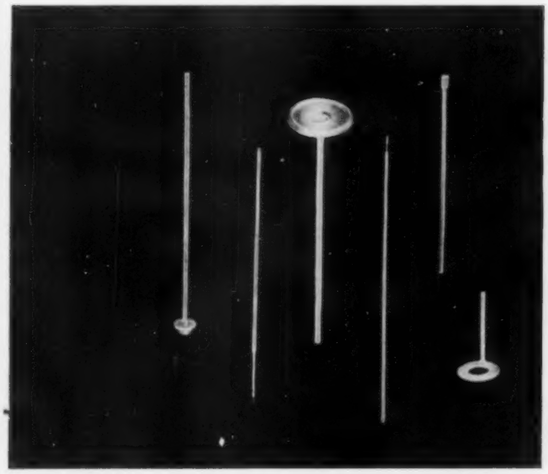




FORMED FROM METAL

Sylvania maintains custom metal stamping facilities, can produce millions of precision-made parts each day from all types of metal. The scope and flexibility of these facilities mean that it can deep-draw eyelets, shells, cups and ferrules. What's more, a battery of multi-slide machines can produce more than 2 million parts daily. Vertical presses can meet daily production needs of 2 million parts. And special, Sylvania-developed machines can produce great quantities of small wire and ribbon forms as well as wire cuts and leads.

Results: Sylvania can supply the parts you need—in high production quantities—of top quality—and at lower cost.



CUSTOM WELDED

If your part is standard-sized, miniature or subminiature, welded assembly is a Sylvania specialty. To help meet your custom assembly needs, Sylvania has developed new high-speed, high-volume welding techniques, advanced welding equipment, automatic and semi-automatic, and a corps of trained specialists.

Result: Sylvania welded assemblies assure high-quality electrical and mechanical contact, mirror-image uniformity, low cost.

CUSTOM ASSEMBLED

Many of our customers have analyzed their parts assembly needs. And they have discovered that Sylvania can often deliver a completely assembled and packaged product—using either all Sylvania components, all customer components or both—at lower cost than is possible within the customer's own facilities.

Result: If your product is small, the parts predominantly plastic and metal, and the quantities 50,000 or more, it pays to have Sylvania assemble it.

*QC MEANS QUALITY CONTROL!

Sylvania maintains a complete quality control department to assure that parts are made to your exact specifications. This control works for you throughout the manufacturing cycle. It's just one more way you benefit when you have Sylvania on the job.

For full details or a quote, write Sylvania Electric Products Inc., Parts Division, Warren, Pa.

SYLVANIA

Subsidiary of **GENERAL TELEPHONE & ELECTRONICS**

GENERAL SYSTEM

For more information, turn to Reader Service card, circle No. 403


HAVE YOU LOOKED INTO
THE DESIGN POSSIBILITIES
OF ROLL-BOND MATERIAL?
Roll-Bond "inflated" aluminum sheet is light, strong, decorative, and leak-proof. It can be designed to float, carry fluids, airs, gas, or wires. And the manufacturing method is so flexible that any continuous tubing pattern you draw on paper can be reproduced in Roll-Bond panels.
Want more facts? Contact Olin Mathieson today for literature and a free preliminary analysis of Roll-Bond in your application: Olin Mathieson, Metals Division, Roll-Bond Products, East Alton, Illinois.
For more Information, Circle No. 437
OLIN MATHIESON METALS DIVISION
Producers of: Roll-Bond, Western Brass and Olin Aluminum

As this heavy-duty milling machine makes a high-speed cut, vital components of AISI 4340 and 4620 nickel alloy steels provide strength and wear-resistance, help maintain precision tolerances.

Two nickel alloy steels . . . 4340 and 4620 . . . give this machine sustained cutting accuracy

Here's how two general-purpose steels used by Kearney & Trecker in their heavy duty **TF** series milling machine have helped that company maintain its famous high-performance standards:

The spindle is made of AISI 4340 nickel alloy steel. This through-hardening steel is quenched and tempered to develop good fatigue strength and high tensile strength with a minimum of distortion. Spindles of 4340 steel resist torsional stresses and wear while maintaining straightness at every running speed.

Gears are precision-cut and wide-faced. They are made of AISI 4620 general-purpose carburizing steel. These gears are carburized and hardened to 58-62 Rockwell "C". What's more, AISI 4620 nickel alloy steel has a tough core to withstand shock loading.

This report is typical of the many coming in from manufacturers who have employed the two General Purpose Steels for a variety of machinery components.

Available right off the shelf from your local Steel Service Center, AISI 4340 and 4620 offer you a two-fisted way to cut costs and still satisfy the majority of your engineering requirements. Other standard nickel-containing steels – providing particular combinations of properties – are also available from your Steel Service Center for your remaining needs.

Consider nickel alloy steels for gears, shafts, bearings and other machine parts you design, order or use. And any time you require engineering information to help you select the right material for your application, write to INCO, outlining your problem. We will be glad to help.

The INTERNATIONAL NICKEL COMPANY, Inc.
67 Wall Street New York 5, N. Y.

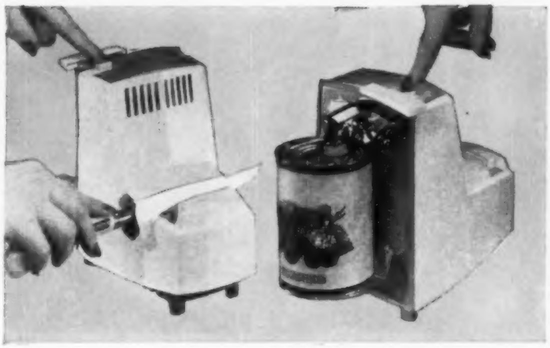
INCO NICKEL

NICKEL MAKES ALLOYS PERFORM BETTER LONGER

IN THE KITCHEN

Pro-fax in the kitchen spells new convenience and satisfaction for homemakers. Knapp-Monarch's Redi-Matic automatic can opener-knife sharpener features a gleaming white Pro-fax housing, and as a result is impervious to damage from staining and rough handling. The Redi-Matic automatically opens cans of all shapes, and sharpens knives of all sizes. Thanks to Pro-fax, it's a luxury styled unit designed to blend beautifully with any kitchen decor.

Molded by: Warren Molded Plastics, Cortland, Ohio.



ABOUT THE HOUSE

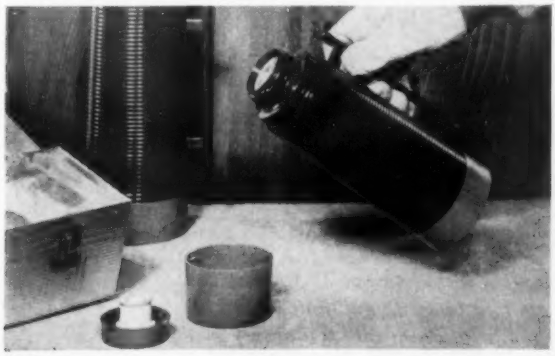
Fast becoming standard home accessories, vaporizers and humidifiers have gotten a big boost in appearance and function by the use of Pro-fax. The new Northern automatic vaporizer/humidifier (shown here) features a bowl and lid molded with Pro-fax, in contrasting colors, which combine in a compact, easy-to-carry appliance that is both useful and attractive wherever it serves in the house.

Pro-fax bowl and lid molded by Cruver Manufacturing Company, Chicago, Illinois.

IN THE NURSERY

Modern style and top performance go hand in hand in Formulette's bottle warmer. It's molded with Pro-fax, of course, for a luxury finish plus resistance to heat and moisture, in a rigid, thin-walled, lightweight unit that is easy to handle, always safe and the ultimate in completely sanitary nursery equipment.

Molded by Boonton Molding Company, Boonton, New Jersey, for Formulette Company, Inc., Jamaica, New York.



IN THE LUNCH BOX

Breadwinners, too, enjoy the convenience and luxury of Pro-fax. The handle, jacket, and collar of Aladdin's new Dura-Clad vacuum bottle, with its unique "Pitcher-Pour" handle, are all molded in one piece with Pro-fax. Pint-size (shown here in use) fits all workmen's lunch kits while the quart size (appearing in the background) is designed to fit conventional outing kits. Both models are heat-, scratch-, and stain-proof.

HERCULES POWDER COMPANY
INCORPORATED
900 Market Street, Wilmington 99, Delaware

HERCULES

CP60-9 THREE NEW MATERIALS FOR THE PLASTIC INDUSTRY

HI-FAX® HIGH-DENSITY POLYETHYLENE • PRO-FAX® POLYPROPYLENE • PENTON® CHLORINATED POLYETHER

For more information, turn to Reader Service card, circle No. 413

1. HOM, a new alloy developed by Duraloy metallurgists and capable of retaining high working strength at temperatures up to 2200°F, with limited application at 2300°F. The alloy is applicable for all types of castings: static, centrifugal, shell-molded.

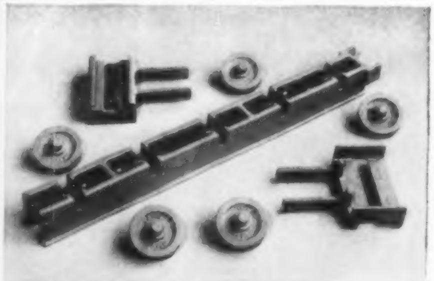
2. Shell-molded castings for meeting close and rigid tolerance limits; post-casting machining or other finishing practically eliminated; low mass production costs.

Illustrating 4 of Duraloy's Major Casting Services

If the casting used in your equipment has to meet high temperature (anything up to 2300°F) and/or corrosion, why not discuss your requirements with our metallurgical staff? Our company can call upon more than 35 years of experience in this exacting business of high alloy castings. In the meanwhile, if you would like to have a copy of our latest catalog, write or call our nearest office.

3. Centrifugal castings which produce a denser, more uniform metal approaching forged metal strength.

4. Static castings which can be produced in weights ranging from a few ounces to single castings 7 tons and heavier; wide range of alloying combinations, including the new HOM referred to above.



Note *As a point of interest, all of the castings shown here were produced for Lindberg Engineering Company, Chicago, for incorporation in heat-treating and annealing equipment sold by that company. The centrifugally cast tube for the generator, trays, and rollers for the furnace rails are cast of HOM. The rails and rail supports for the furnace are statically cast of 35-15 alloy.*

ALLOY CASTING INSTITUTE ACI MEMBER

The DURALOY Company

OFFICE AND PLANT: Scottdale, Pa.

EASTERN OFFICE: 12 East 41st Street, New York 17, N. Y.
CHICAGO OFFICE: 332 South Michigan Avenue
DETROIT OFFICE: 23906 Woodward Avenue, Pleasant Ridge, Mich.

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For more information, circle No. 431 ➤

stainless steel

No other metal has the strength, beauty and versatile qualities that serve you so well today and promise so much for tomorrow.

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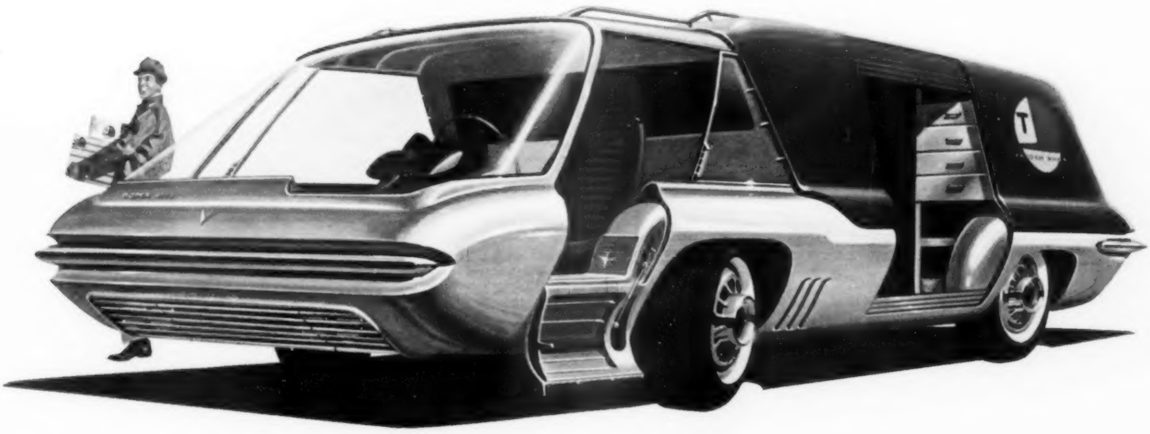

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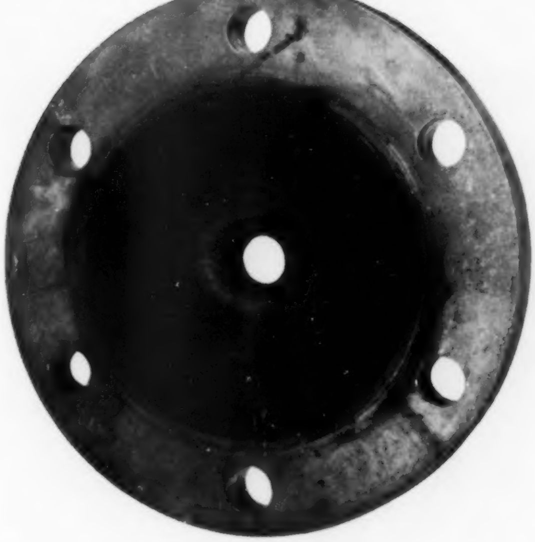

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	Copper	AMZIRC
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Total runs	4679 cycles	6941 cycles
Condition on removal	deep heat checking, orifice enlarged from 0.562" to 0.572"	no heat checking, orifice enlarged from 0.562" to 0.572"

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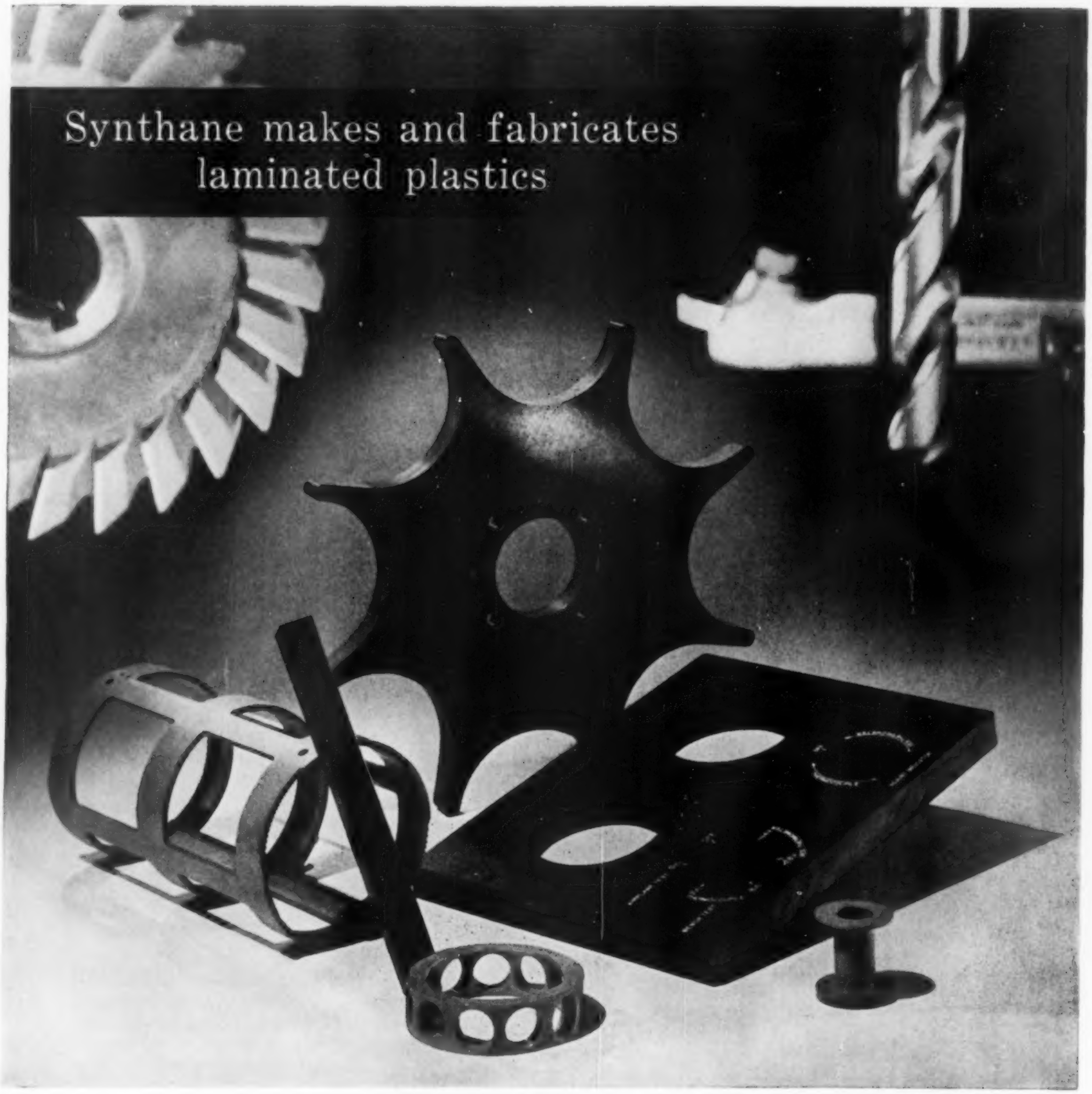

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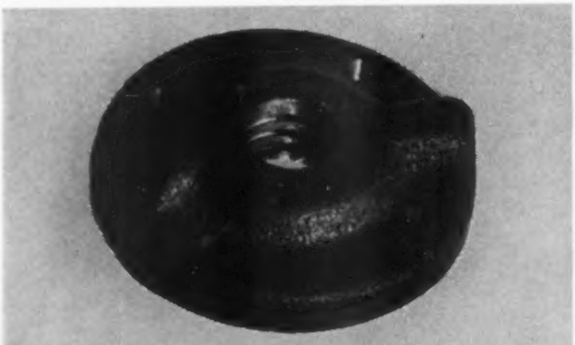
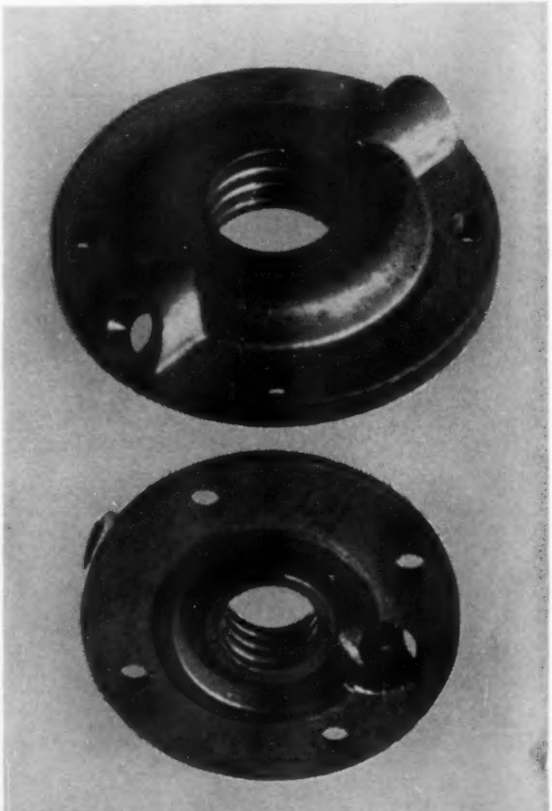


Cast iron retainer ring



Upper and lower surface of the same casting in zinc

Eliminate costly machining operations. Improve your product. That's precisely what St. Louis' Baldor Electric Co. did when they switched to zinc alloy die castings for their electric motor bearing lock rings.

Formerly the rings were sand cast in iron. To complete each ring required four machining operations: 1. Face milling; 2. Machining of a locating ring groove; 3. Boring a shaft hole; 4. Drilling screw holes. Other disadvantages of the sand castings included dimensional inaccuracy, rough appearance and a high reject rate due to porosity.

The switch to zinc die castings brought advantages which more than offset the difference in cost of basic material:

1. Elimination of machining.
2. Higher speed of production.
3. Close "as cast" dimensional tolerances.
4. High corrosion resistance.
5. Superior appearance.

The rings are die cast to exact size, with the bore holes and locating rings held to .002". The cored screw holes are cast to size in the same operation. They are cast in three sizes by the A. B. Mueller Co. of St. Louis, Mo. Each size is cast in a two-cavity die as annual production requirements are 36,000 of each size at the rate of 160-180 shots per hour.

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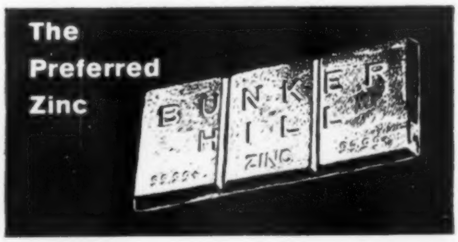

ZN-186

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working with

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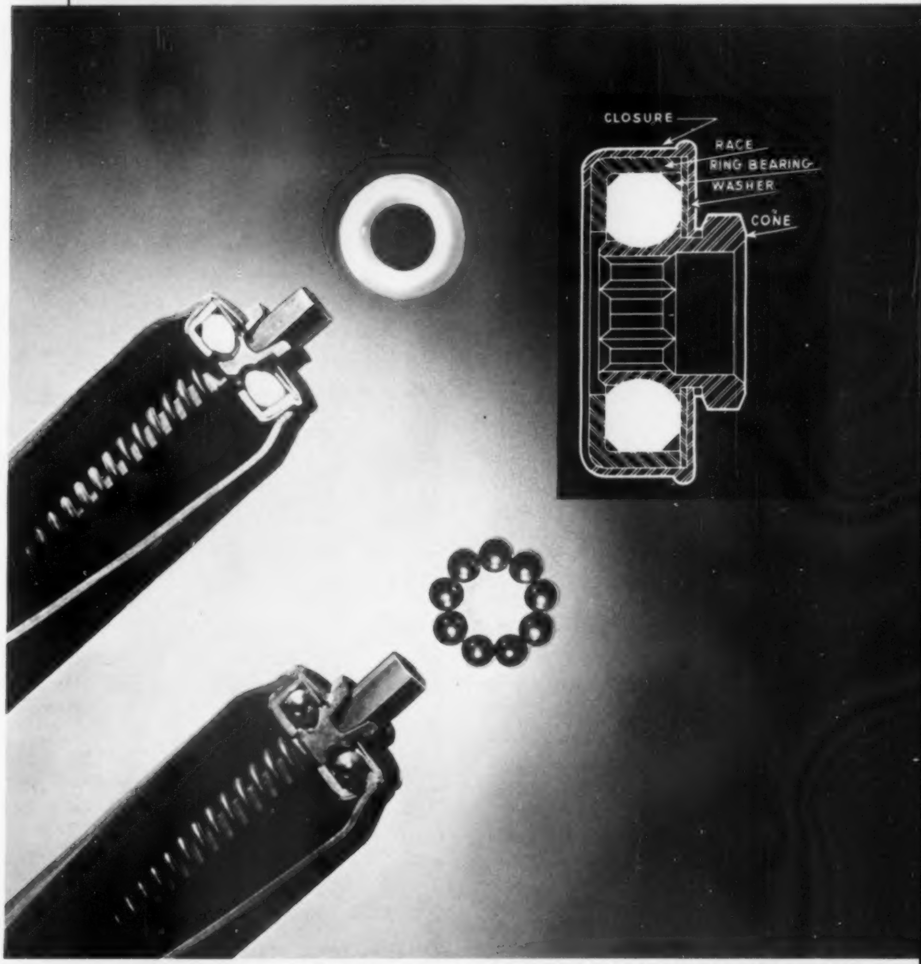
one of Du Pont's versatile engineering materials



Ring bearings molded by Sinko Tool and Manufacturing Co., Chicago.

Ring bearing illustrates why Delrin® is doing so many jobs once reserved for metals

The use of roller and wheel conveyors in manufacturing, wholesale and retail business has become commonplace today. But as universal as their use is, they have remained relatively noisy mechanisms.

This objection prompted the Rapids-Standard Co., Inc., Grand Rapids, Mich., to seek a new material to replace the steel balls in the bearings of their conveyors. Their choice was rings of "Delrin" acetal resin (roller conveyor shown above). With "Delrin", the conveyors are now "virtually noiseless". The bearings require no lubrication in service, and they will not corrode in normal use. In addition, weight savings of 50-65% have been realized.

This ability of "Delrin" to compete with steel, die-cast zinc and aluminum, cast and machined brass, and cast iron (see reverse side for additional examples) stems from its unique combination of physical properties and design-production economies. With "Delrin", manufacturers are discovering new ways to improve product performance—often at lower cost.

• • •

We will welcome the opportunity to assist you in evaluating how "Delrin" can bring these advantages to your products. A coupon appears on the reverse side for your convenience.

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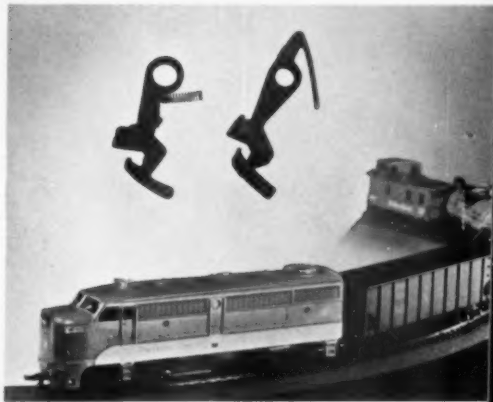
one of Du Pont's versatile engineering materials

These typical end-uses reveal performance and cost advantages of Delrin®



The Lionel Corporation, Irvington, N. J., recently introduced a new HO train line featuring a one-piece coupler molded of "Delrin". Because "Delrin" has the resilience to provide the desired springing action, Lionel designed the integral unit to replace a two-part assembly of coupler and coil spring. The result: a significant assembly saving plus a new sales feature. "Delrin" is also used for the axles, journals and two other truck parts. (Molded by Lionel and Gries Reproducer Corp., New Rochelle, New York.)

The head frame (top) of the new "Lady Ronson" Superbe electric shaver is molded of "Delrin", saving 80% of the weight of the previous gold-plated die-cast zinc part. Ronson Electric Shaver Corp., Stamford, Conn., specified "Delrin" because it could be molded to and hold the necessary dimensions, have a smooth luster without finishing and resist body oils and colognes.

Four parts (in white) of this self-seating faucet are molded of "Delrin", saving 80% of the cost of the machined brass components formerly used by the Kel-Win Manufacturing Co., Inc., Richmond, Va. Kel-Win chose "Delrin" because it resists corrosion and mineral buildup, remains dimensionally stable and eliminates machining operations and rejects. (Molded by Dominion Plastics Co., Colonial Heights, Virginia.)

"Delrin" acetal resin offers designers such properties as strength, stiffness, dimensional stability, resilience and abrasion resistance; and it retains these properties even under exposure to wide variations in temperature, humidity, solvents and stress. Already hundreds of designs taking advantage of these properties, and of the cost savings made possible by rapid injection molding, have been specified or put into commercial production. We suggest that you investigate how "Delrin" can be profitably used in the products you make and the products you use. Commercial processors and our own staff of technologists are ready to assist you.

POLYCHEMICALS DEPARTMENT

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ENGINEERING & DESIGN

...AT A GLANCE

Some missile and space vehicle design problems may be solved as the result of a new, $12 million research program aimed at finding new types of graphite and graphite-based materials. Uses for such materials will be rocket nozzles, nose cones, leading edges, and other hot spot applications. Main objective of the program is to explore raw materials and processing techniques that will significantly reduce variations in the mechanical and physical properties of graphite. Another objective is to reduce total manufacturing time for graphite from many weeks to several days.
Source: National Carbon Co., Div. of Union Carbide Corp., 270 Park Ave., New York 17.

Efforts to improve the heat resistance of nylon by adding stabilizing compounds have thus far been only partially successful. Studies show that the heat stability of nylon 6 molding compound is considerably improved by adding conventional antioxidants. However, it is unlikely that there will be a generalized solution to the problem; rather, each nylon resin will probably require a careful experimental program to determine how it may be stabilized against deterioration.
Source: M. M. Epstein and C. W. Hamilton, Battelle Memorial Inst., 505 King Ave., Columbus 1, Ohio.

High temperature structural strength of tungsten can be maintained at temperatures exceeding 3000 F by coating the metal with a vitreous-type bonded refractory in which zircon is bonded with a high temperature glass.
Source: C. G. Bergeron, University of Illinois, Dept. of Ceramic Engineering, Urbana, Ill.

Alloys suitable for use in fuming nitric acid at temperatures up to 160 F are aluminum alloy 6061, and stainless steel types 304, 347 and 17-7PH. The alloys were selected on the basis of service life, ease of fabrication, weldability and mechanical properties.
Source: E. J. Kinsley, Bell Aircraft Corp., Buffalo 5, N. Y.

Beryllium machines like cast iron but is more abrasive on tools. Its brittle behavior can cause spalling at the exit of cuts, and cracking at the surface. During machining, pieces of built-up edge can slough off the tool, causing a scuffed, machined appearance. Carbide tools seem best for turning, milling and drilling beryllium at speeds up to 250 fpm.
Source: Rpt. No. PB 161171, Office of Technical Services, Dept. of Commerce, Washington 25, D. C.

Fluxes used in tinning aluminum alloys can cause intergranular cracking. However, recent research shows that electroplating or ultrasonic tinning permits the application of tin to aluminum alloys without danger of intergranular cracking.
Source: C. L. Carlson, Westinghouse Electric Corp., Materials Engineering Depts., East Pittsburgh, Pa.

Tensile properties and hardness of spun metal parts increases with increasing reductions and elongation decreases. Data comparing the effects of mechanical and hand spinning methods on the properties of spun parts show that mechanical spinning produces a part with more uniform strength than parts produced by hand spinning. However, hand spinning produces a part with more uniform deformation. Properties of mechanically spun metal parts are similar to those produced by cold rolling to the same reduction.
Source: S. Floreen and others, University of Michigan Research Inst., Ann Arbor, Mich.

For more information, turn to Reader Service card, circle No. 372

High Energy Rate Forming Processes
—Their Present and Future

A limited production tool now, high energy forming methods are being explored for forging, welding, sheet metal forming, and powder metallurgy.

by Donald Peckner, *Associate Editor, Materials in Design Engineering*

■ Use of extremely high energy methods for processing and fabricating metals is an accomplished fact. Parts can and are being produced on a production basis.

On the other hand, the methods used are still empirical. Research programs now are underway to obtain data which will permit accurate control and specification of the process variables.

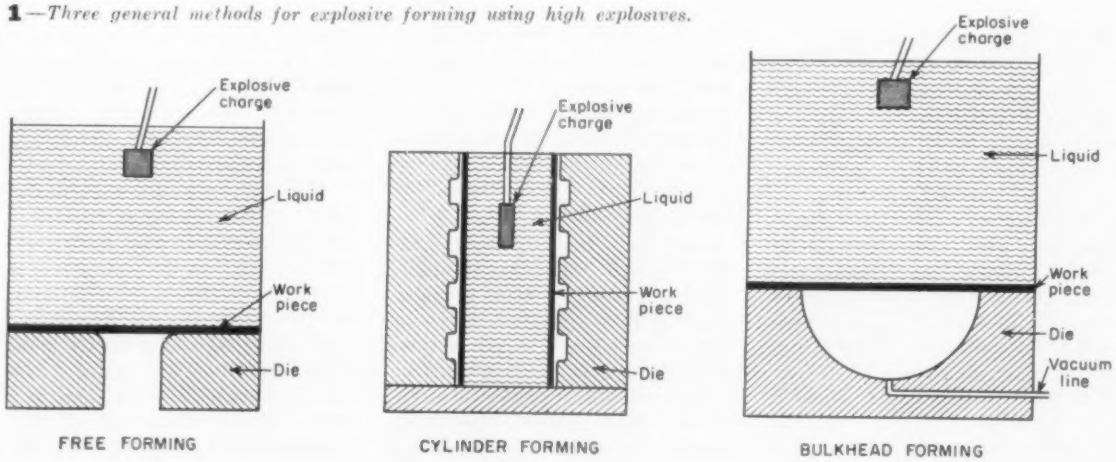
The principal advantages of high energy rate forming are:

1. Parts can be formed which cannot be formed by conventional methods.
2. "Exotic" metals, which do not readily lend themselves to conventional forming processes, may be formed over a wide range of sizes and configurations.
3. Excellent for restrike operations.
4. Springback after forming is reduced to a minimum.
5. Dimensional tolerances are generally excellent.
6. Variations from part to part are held to a minimum. Process is extremely reproducible.
7. Scrap is low.
8. Less equipment and fewer dies cut down on production lead times.

Briefly, in high energy rate forming, parts are shaped by the extremely rapid application of high pressures. Pressures running as high as 2,000,000 psi and speeds as high as 3000 fps may be used.

A number of high energy forming systems have been developed. They include methods making direct use of the energy from detonated high explosives (explosive forming), expanding gas (cartridge) systems, high pressure gas forming (Dynapak), and hydrospark forming. All these methods except hydrospark forming are now being used in commercial production. Each of the methods is covered in this article.

1—*Three general methods for explosive forming using high explosives.*

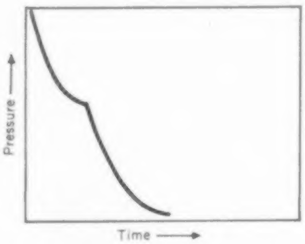


The Principles of High Energy Forming

Several parameters must be considered in a discussion of high energy forming: 1) the load itself, including its magnitude, duration, and distribution; 2) mechanical properties of the material and the effect of rapid deformation on these properties; 3) geometry of the part being formed; and 4) space and time distribution of the load within the part.

The impulsive load

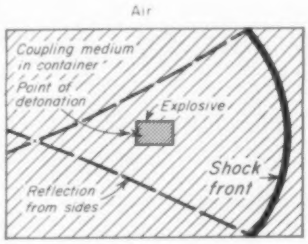
An impulsive load, as found in explosive forming, has several characteristics (see below):



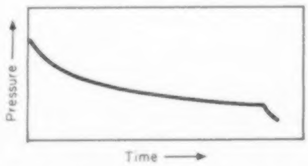
A—*General profile of transient disturbance generated by an impulsive load.*

it increases to a high stress value almost instantaneously (less than a microsecond); it rapidly decreases in magnitude; and the total time it is effective is measured in microseconds.

To reduce the possibility of fracturing the work piece, and to aid in explosive forming, the pressure-time relationship should be modified to lower the pressure peak and increase loading time. A setup to promote these modifications and a modified pressure-time profile are shown below.

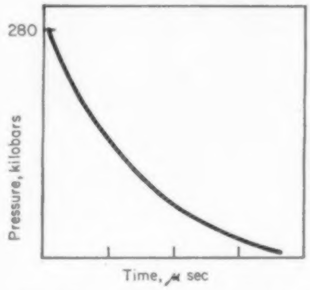


B—*Detonating explosive in a container will modify shock waves.*



C—*Peak pressure is modified, applied for longer time when shock waves are modified.*

When an explosive is detonated, the pressure rises in a fraction of a microsecond to a very high value (approximately 300,000 atm) and then decays rapidly—in a few microseconds—because the gaseous products of the explosion expand and bleed away. A pressure vs time curve (see Fig C) at a particu-



D—*Pressure time curve for typical explosion.*

lar point on the loaded surface of a body depends both on the shape of the specimen and the shape of the applied explosive charge. Since metals are not completely rigid, they react to the pressure generated by the explosion. The nature of the reaction is complex and not completely understood at this time.

Pressure at the interface, as viewed from within the steel plate, is about 280,000 atm; the initial velocity of the steel surface is 2260 fps. Disturbances propagate at different rates in different materials. A similar figure for lead is 2590 fps.

Explosive forming

There are three different explosive forming techniques now being used: free forming, bulkhead forming and cylinder forming. The schematic drawings in Fig 1 show how these three methods are used for sheet metal forming. Both free forming and bulkhead forming allow the work piece to be heated before forming. It is obvious that heating prior to forming cannot be specified when the cylinder forming method is used.

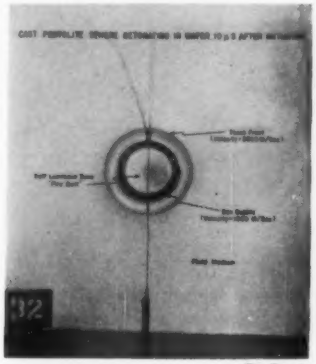
Although air can be used as a coupling medium between the explosive and the work piece, in most cases water is used. An analysis of explosive efficiency by Lockheed Aircraft Corp. indicates that efficiency in air is approximately 4%; the corresponding figure for water is 33%.

Explosive forming today has the status of an art, with vigorous attempts being made to transform it into a science. Much of the experimental work is performed on a trial basis. Various factors such as mechanical properties of the material, type of explosive, pressure-transmitting medium and distance of explosive from work piece must be varied individually until the combination necessary to successfully produce a part is determined.

Material constants

Materials that have been explosively formed range from aluminum alloys to the refractory metals. All can be formed into various configurations, depending on the forming conditions.

Work performed at the National Northern Div. of American Potash and Chemical Corp. indicates that initial elongation of the material is directly related to ex-



Du Pont

E—*Initial stages of growth of shock wave and gas bubble 10 microseconds after detonating a sphere of high explosive in water.*

The explosion shown in the illustration above shows how rapidly the explosive force is applied to the metal blank. Five factors that affect the shape and strength of the pressure pulse are: weight of explosive, charge geometry, type of explosive, transmitting medium and distance between explosive and work piece.

Stress and velocity

The stress required to rupture the materials is called the critical normal fracture stress, σ_c. In explosive forming this stress is of primary concern. Values of σ_c for five metals are given in the table.

A critical velocity exists at which permanent deformation will begin to occur on the surface impacted by the shock front. A velocity of fundamental importance in explosive forming is that at which fracture first begins at the point of impact—the critical impact velocity. Values of critical impact velocity are also given in the table.

CRITICAL PARTICLE VELOCITY AND NORMAL FRACTURE STRESS FOR FIVE METALS

Metal ↓	Particle Velocity for Fracture, fps[a]	Associated σ_c, 1000 psi[b]
2024 Aluminum	202	140
Copper (annealed)	264	410
Brass	216	310
AISI 1020 (annealed)	84	160
AISI 4130 (annealed)	235	440

[a]Differential particle velocity needed to cause fracture.
[b]Critical normal fracture stress.
Source: *J. S. Rinehart.*

By analogy with elastic waves, it can be assumed that the velocity of propagation of a plastic strain of particular magnitude (in the tensile impact test) depends on the shape of the stress-strain curve at that value of strain. The velocity of propagation, C, of a particular magnitude of strain is:

$$C = \sqrt{(d\sigma/d\epsilon)/\rho}$$

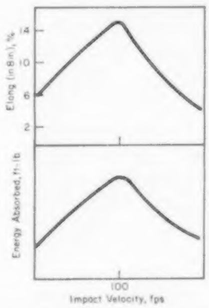
where $d\sigma/d\epsilon$ is slope of stress-strain curve at value of strain considered, and ρ is mass density.

The impact velocity, V, that will produce strain ϵ is given by:

$$V = {}_0\int^{\epsilon} \sqrt{[(d\sigma/d\epsilon)/\rho]d\epsilon}$$

When strain reaches the value ϵ_u, corresponding to the ultimate strength of the material, $d\sigma/d\epsilon$ becomes zero and rupture occurs. The energy required for fracture drops suddenly when the velocity of the applied tension is greater than the critical impact velocity, as shown below.

In general, an increase in the rate of deformation will raise: 1) the yield strength, 2) the entire stress level of the flow curve, and 3) the ultimate strength of the material. For common metals these increases are of the order of 10 to 20%.



F—*Effect of impact velocity on the elongation of mild steels. Critical impact velocity, in this case, is 100 fps.*

(After Clark and Wood.)

plosive (or high energy rate) formability. The formability equation developed by National Northern is:

$P_e = K_m$ (% elong, temp, transmitting medium, type of explosive)

Where:

P_e=The maximum amount of plasticity available through explosive forces without rupture of the work piece.

K_m=A material constant (which must be determined for each family of materials).

% Elong=The mechanical property normally determined in tensile test.

Temp=Temperature of the work piece. (Plasticity is related to temperature in explosive forming, just as in conventional forming).

Medium=The medium used to transmit the explosive force (air, water, etc.).

Explosive=Type of explosive used for generating the forming force. This is a function of plasticity since different explosives have different pressure-time pulses which affect the rate of stress application.

The factor K_m is the ratio of elongation of the formed part to elongation as determined by the tensile test. Several K_m values determined at National Northern are:

Nickel	1.0
Stainless steel	1.1
Titanium	1.5
Plain carbon steels	2.3
Aluminum	2.5
Tool steels	>2.0
Magnesium	>2.0

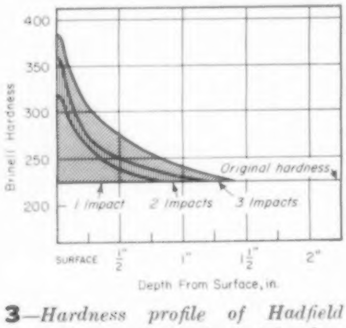
This parameter is being determined for: copper alloys, molybdenum, tungsten, columbium, beryllium, tantalum, uranium and Zircaloy-2.

National Northern Div., American Potash & Chemical Corp.

2—*Stainless steel jet engine liners, 43 in. dia. Explosively formed, tolerance between dimples is ±0.010 in.*

National Northern Div., American Potash & Chemical Corp.

4—*Various stages in explosively forging an aluminum aircraft part.*



3—*Hardness profile of Hadfield steel after explosive impact hardening. As expected with a work hardening material, hardness increases as more work is done.* (Du Pont)

TABLE 1—ROCKWELL HARDNESS OF EXPLOSIVELY FORMED PARTS STRETCHED 30-35%

Condition ➡ / Metal ⬇	Before Forming	After Forming	After 35% Cold Work*
"A" Nickel	62B	99B	98B
Inconel	80B	102B	95B
Inconel "X"	18C	30C	—
Monel	68B	95B	90B
AISI 1020 Steel	72B	100B	85B

Source: National Northern Div., American Potash & Chemical Corp.
*Data added by author.

Tolerances

Tolerances cannot be expressed quantitatively at this time. At least one company has stated that springback was eliminated on explosively formed parts. Other companies have found that the springback problem is similar to that encountered in conventional forming. Fig 2 is a photograph of a J93 jet engine liner, 43 in. in dia. The tolerance maintained between dimples is ±0.010 in.

Work now being performed by many companies and other work contracted by the Air Materiel Command will undoubtedly develop a rigorous set of tolerances to be applied to explosive metal forming.

Effect on properties

Changes in mechanical properties caused by explosive forming correlate closely with those obtained in material cold worked to the same degree. Tests on explosively formed nickel alloys, performed at the National Northern Div., bear this point out as shown in Table 1. The table compares hardness before and after explosive forming.

Surface hardening

In addition to sheet metal forming, other uses of high energy rate processes show promise. Explosive impact hardening will find use in components made from a material which is hardened by cold work (austenitic stainless steel, Hadfield steel, nickel, molybdenum, etc.). One probable specific area of application: restoring mechanical properties of parts that have been welded or heat treated—and thus softened to some extent—after cold working.

Hardness can be controlled by varying the weight of explosive used in any one impact, as well as varying the number of impacts. Fig 3 shows the hardness variation obtained in Hadfield manganese steel with increasing number of impacts.

Surface of the piece being hardened will be depressed by the application of the explosive. Du Pont has found that typical surface depression, using 2 gm per sq in. of sheet explosive is:

No. of Impacts	Depression per impact, in.	Total Depression, in.
1	0.010	0.010
2	0.008	0.018
3	0.005	0.023

Table 2 presents mechanical properties of three austenitic stainless steels after explosive impact hardening.

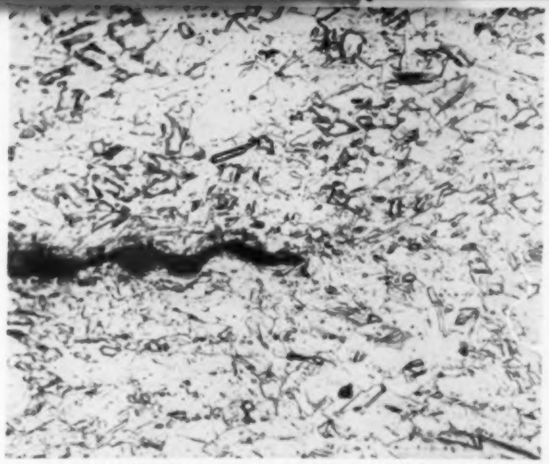
Powder compacting

Both single- and double-acting explosive presses (rams actuated by explosives) have been devel-

TABLE 2—EXPLOSIVE IMPACT TREATMENT AFFECTS MECHANICAL PROPERTIES OF STAINLESS STEEL

	Before Explosive Treatment			After Explosive Treatment		
Stainless Type ➡	302	304	316	302	304	316
Yld Str, 1000 psi	27.5	30.5	26.7	142	154.0	127.0
Ten Str, 1000 psi	88.0	95.0	77.7	154	180.0	147.0
Elong, %	84	81	72	19	25	17
Red. in Area, %	80	78	79	62	46	60

Source: E. I. du Pont de Nemours & Co., Inc.



National Northern Div., American Potash & Chemical Corp.

5—*Explosives weld copper-to-copper at room temperature. Void on left deliberately introduced to show that bond is metalurgical, not mechanical.*

National Northern Div., American Potash & Chemical Corp.

6—*Tubes are mechanically bonded as liners (top row). A dimpled sheet and cold welded assembly are shown in the same row. Second row: several aluminum forgings. Bottom row: designs can be embossed on metal using explosives.*

Two Kinds of Explosives

Two general types of explosives are being used in explosive forming.

Low explosives: Deflagrating explosives (smokeless powder, black powder, etc.) are characterized by a burning rate which can range up to hundreds of feet per second. Pressures can range from 100,000 to 300,000 psi but the necessary tooling is elaborate and expensive.

High explosives: Detonating explosives (dynamite, TNT, RDX, PETN, etc.) are characterized by a reaction zone traveling through the explosive at velocities of several thousand feet per second. Since the reaction occurs in microseconds, high explosives release their energy at a constant rate, no matter how they are confined, and a shock front with a pressure close to 2,000,000 psi is generated. Because the amplitude and shape of the pressure pulse behind the shock front can be closely controlled, Du Pont has stated that it prefers to use this type of material for explosive metal forming.

oped to determine the feasability of producing powder metallurgy parts. In addition to powder metallurgy, some other experimental areas have been studied at the Naval Ordnance Test Station, China Lake, Calif., including: effect of explosive powder forming on changes in material properties, increasing the packing density of materials such as graphite (to prepare a neutron absorber of uniform density), cold bonding of dissimilar materials, and bonding of particles of low ductility that cannot be bonded by normal rolling methods and shaping powders.

Forging

National Northern Div., American Potash and Chemical Corp., recently conducted a study of explosive forging for the Air Materiel Command. As a result of the study, the following conclusions were drawn:

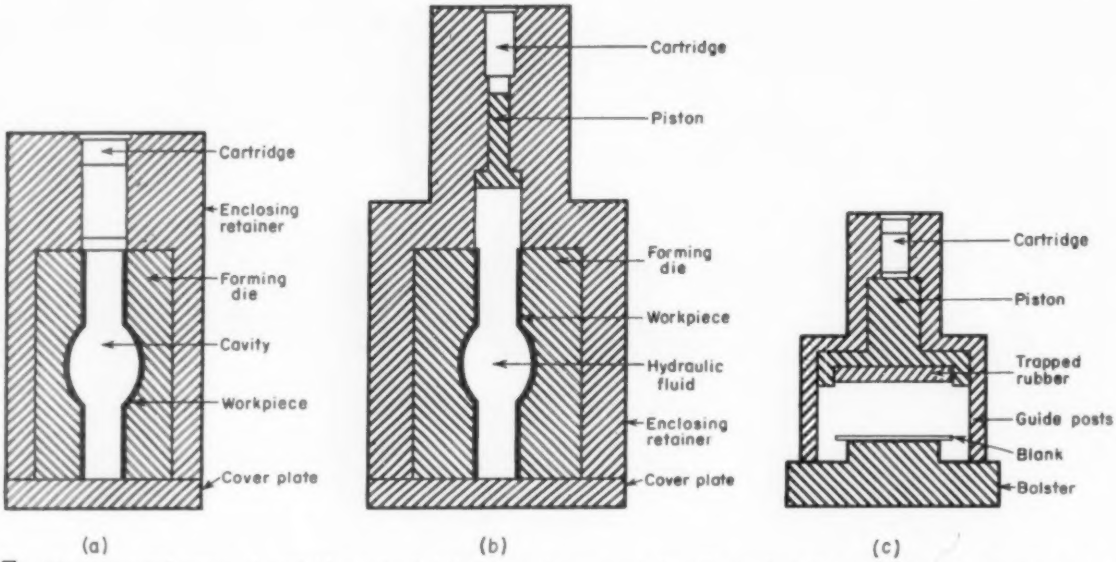
1. Aluminum alloys can be explosive forged if the design has no extreme contours.
2. Forgings can be produced with a high degree of reliability.
3. Tough, hard dies are necessary for the forging operation.
4. High explosives provide the most efficient available force for forging.
5. The explosive should be fired at a short stand-off distance, and be contained in such a manner that forces that normally would not strike the stock are reflected onto the stock, and have a geometry approaching the part geometry.
6. It is desirable to maintain the pressure for milliseconds rather than microseconds.
7. Mechanical properties of the forgings are higher than expected typical properties. In one case, the determined tensile strength (85,000 psi) and elongation (15%) were, respectively, 7% and 30% higher than quoted typical properties.
8. Costs of explosively produced forgings exceed those of forgings produced conventionally.

Fig 4 is an example of an explosively forged part. Note that this part is produced with a minimum draft angle and is forged only on one side.

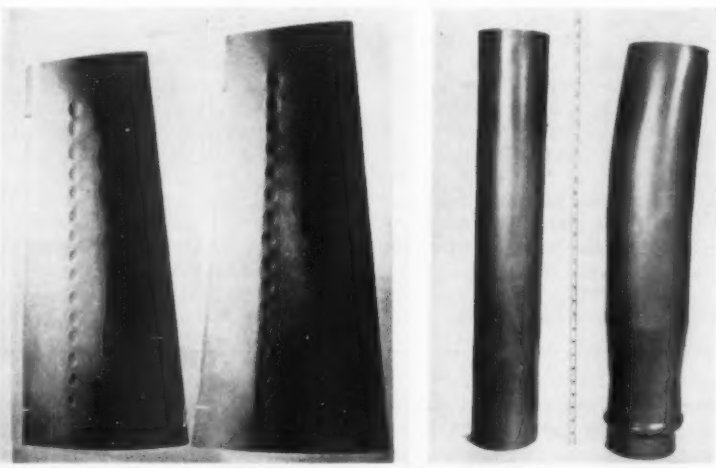
Welding and bonding

Cold welding and mechanical bonding can be achieved under the high pressures generated by explosives. This is an area still in the early stages of exploration. Fig 5 is an example of a copper-to-copper weldment produced explosively. The metallurgical, not mechanical, bonding occurs. The fusion line is barely discernible to the right of the void as a cold worked area.

Fig 6 contains examples of tubes bonded by explosive expansion. Note that a shoulder is usually explosively formed to lock the bonded material into place. The photograph shows several other types of explosive forming operations, including forging, embossing, dimpling, and welding.



7—*Three general types of cartridge actuated devices: a) gases act directly against the workpiece; b) pressure acts through a hydraulic system; c) gases act on piston.*



Winchester-Western Div., Olin Mathieson Chemical Corp.

8 *(left)—Titanium jet engine inlet guides formed by cartridge actuated device. Ten in. long, the guides taper from 5½ in. on large end to 3½ in. on small end. Tolerance of ±0.010 in. was maintained and springback minimized. Heated to 1000 F before forming.* **9** *(right)—Sound suppressor tube 31 in. long is made in cartridge actuated device.*

Expanding gas methods

Explosive forming methods making use of expanding gases are closely related to the explosive forming techniques just described. Gases generated by the burning of propellant powders in a closed container produce the pressures required to form metals. Most of the work that uses propellant powder gases as the energy source is classified as bulge-type forming. Several types of cartridge-actuated dies are shown in Fig 7.

In each die, which is completely closed, the gases expand directly against the work piece, forcing it to accept the contour of the female die (or be bent over a male die). There are two variations: 1) the expanding gases may press against some intermediate medium (Fig 7b) which, in turn, presses against the work piece; or 2) the expanding gases actuate a piston (Fig 7c) that acts on the intermediate medium which ultimately forms the work piece to the proper configuration. Several parts formed by these methods are shown in Fig 8 and 9.

Dynapak process

Development of Dynapak brings high velocity metal parts production, formerly requiring use of explosives, into the metalworking shop. The new machine can be operated by relatively unskilled labor and produces parts at rates as high as 120 per hr.

Although the underlying principles are not fully understood, it is believed that many metals, including the high strength steels, exhibit plastic flow when they are worked at high velocities. Explosive forming is being used to take advantage of this phenomenon, and, as pointed out in preceding sections, a number of or-

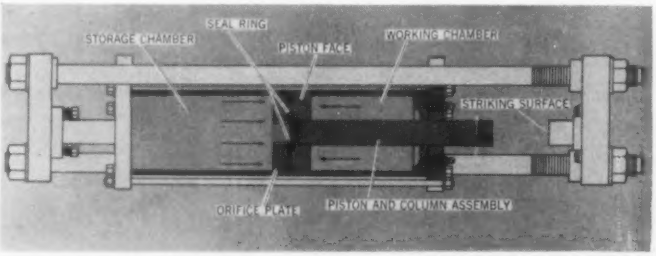
How the Dynapak Machine Works

The Dynapak machine (below) is essentially a cylinder separated into two chambers by an orifice plate. A piston in one chamber (right) is connected to a thrust column which acts directly on the material being formed. The other chamber is a storage reservoir for high pressure gas. A small seal ring is placed on the face of the piston, contacting the orifice plate.

In operation, the chamber containing the piston is pressurized at a low value, thus forcing the piston against the orifice plate and isolating the face from the storage chamber except for the small piston area within the ring seal. Since the available piston area is small, equilibrium is reached only by pressurizing the storage chamber to a high value.

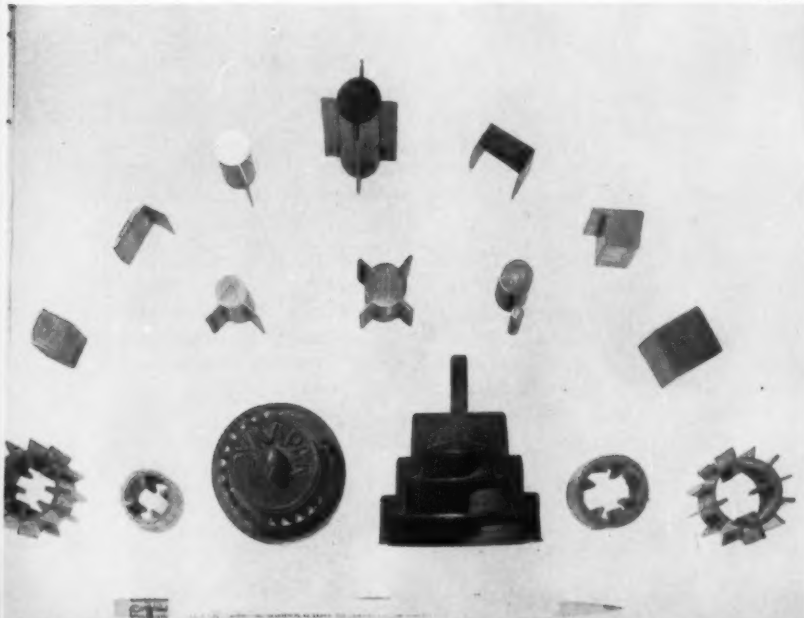
With pressures balanced, the machine is ready to operate and form the part. Upsetting the balance triggers the machine. This is accomplished by slightly increasing the pressure in the high pressure chamber. The change in pressure upsets the equilibrium and the piston starts to move toward the right, thus removing the seal from the orifice and permitting the high pressure gas to push against the entire piston face. As a result, the force is greatly unbalanced and the piston moves to the right with almost explosive velocity. The full stroke of the piston occurs in a few milliseconds. The high energy level, applied to the material being formed, drives the material into the female die and forms the part.

The operation can be illustrated by the following example: Assume that the piston face has an area of 10 sq in. and the orifice has an area of 1 sq in. Suppose the cylinder on the right is pressurized to 200 psi. To balance this pressure, it is necessary to pressurize the left cylinder to 2000 psi; the pressure on the piston face (left) is applied to only 1 sq in. whereas that on the right is applied to 10 sq in. of surface. Now raise the pressure in the high pressure cylinder by 1 psi. The piston starts to move and before it has moved as much as a thousandth of an inch, the orifice is unsealed and the entire 2001 psi pressure is applied against the piston face (10 sq in.). The force operating on the piston face is increased to 20,010 lb and this force acts against the 200 lb behind the piston completely overbalancing it and forcing the piston to move rapidly to the right.



Dynapak essentials *are shown in cross-sectional view of machine. Text explains how machine works.*

10—*Many configurations can be formed by the Dynapak. Two forgings in lower center have zero draft angle. Extrusion walls can be made thinner.* Convair



ganizations have achieved good results in forming parts by this method. However, the method has certain disadvantages—primarily the potential hazard of handling explosives, the low production rate, and the fact that tolerances apparently are not as close as desirable.

The Dynapak machine uses a gas-powered ram to form the part and the operation is under close control. The principle of operation is discussed in an adjoining box. This machine has the following advantages:

1. Low cost. A $3 cylinder of nitrogen will operate the machine for a day.
2. Rapid production. Cycle time ranges from 30 to 60 sec.
3. The machine can generate high energy levels and velocities

above 200 fps. Velocities can be controlled within 2 fps.

4. Simplicity of operation. An operator merely manipulates a dial.

5. Dies can be made of ordinary steel.

6. Parts can be extruded, forged, formed or compacted.

7. Parts can have zero draft angles with minimum curve and fillet radii.

Materials and applications

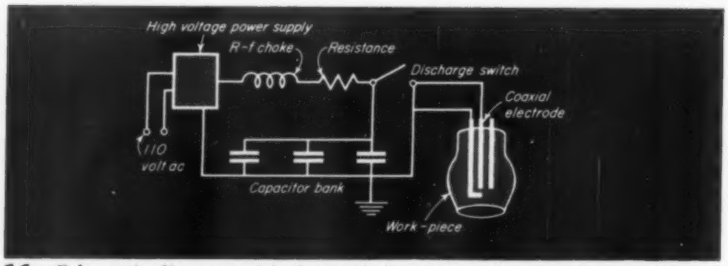
Dynapak can form low alloy steels such as 4340, austenitic steels of the 200 and 300 series, titanium, and the refractory metals, to name a few examples. It can also be used to compact powders to a density higher than normally obtained with conventional powder metallurgy presses.

Sheet of difficult-to-form alloys has been formed to deep contours by the machine. It has also been used for precision shearing and blanking, using a one-piece die.

Parts have been extruded with excellent surface finish and close dimensional tolerances. Web thicknesses of 0.01 in. can be obtained. Wire 0.020 in. in dia has been extruded directly from a 1-in. billet.

Hot and cold forgings of various materials can be produced with zero draft angles and minimum radii. The smooth, close tolerance surfaces that are produced often minimize finish machining requirements.

Fig 10 shows a variety of parts produced on the Dynapak machine.



11—*Schematic diagram of hydrospark forming system.* (Republic Aviation Corp.)

12—*Aluminum tubes are bulged. Force is provided by spark discharged at voltages ranging from 7.5 kv to 22.5 kv.*

Republic Aviation Corp.

Hydrospark forming

Explosives are not the only means of achieving a high deformation rate. In hydrospark forming a spark is discharged in a nonconducting liquid medium and generates a shock wave that travels at the speed of sound from the spark source to the work piece. A schematic diagram of the hydrospark system is shown in Fig 11.

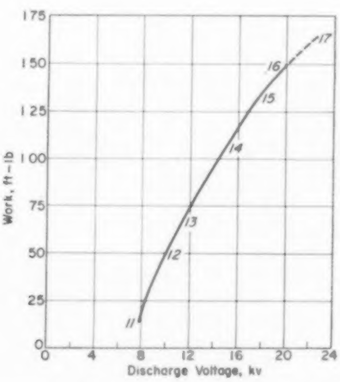
A series of bulge-formed aluminum cylinders is shown in Fig 12. Voltages ranged from 7.5 kv to 22.5 kv. Fig 13 shows the work applied to each cylinder as a function of discharge voltage.

According to engineers at Republic Aviation Corp., hydrospark forming offers several advantages:

1. Explosives, with their potential safety hazard, are eliminated.

2. Parts can be sized into a die by several applications of energy impulses. Since the device is electrical, components of the system do not have to be repositioned after each shot.

3. A standard machine tool, based on hydrospark forming principles, can eventually be constructed for about one-tenth the cost of a conventional hydraulic press and occupy only a fraction of the floor space.



13—*Work performed on bulged tube shown in Fig 12.* (Republic Aviation Corp.)

Bettinger Corp.

Giant globe *consisting of 21 different colors (on 584 separate panels) is a good example of porcelain enamel's decorative possibilities.*

Goodyear Tire & Rubber Co.

Landmark sign *for Goodyear's identification program uses highly decorative background of black porcelain enamel over expanded metal.*

Properties of Porcelain Enamels

by William E. Pierce,
Manager, Product Engineering,
Porcelain Enamel Institute

Porcelain enamels can be formulated in hundreds of different ways to meet the demands of a wide range of applications. Here is a comprehensive survey of the important decorative and functional properties you can obtain with this durable finish.

1. Appearance properties

Hiding Power

Varies with enamel thickness and composition. Best hiding power is exhibited by super-opaque, titanium-bearing enamels which provide satisfactory appearance at thicknesses as low as 3 mils.

Some coatings may be deliberately designed to have poor hiding power, as in the case of clear frits used in colored enamels which are applied over a white undercoat for decorative effect.

Gloss

A measure of specular reflectance. Although commonly referred to by terms such as shine or luster, gloss can be scientifically scaled in tests like the 45°-45° specular gloss test. On this scale a polished black enamel has a value of about 55, and most glossy enamels on sheet iron will fall in the range of 50 to 60. However, values can range from as low as 1 for some matte enamels up to 85 for some lead-bearing enamels.

Light Reflectance

A measure of "whiteness." It is measured as the luminous daylight 45°-0° directional reflectance. A porcelain enamel is usually required to have reflectance of at least 65% to be considered white, and most white enamels have a reflectance of at least 75%. White porcelain enamels for light reflectors usually have a total reflectance of at least 80%.

Texture

A wide variety of textures have been made available in recent years. Ordinarily, porcelain enamel has a smooth, fire-polished surface with slight waviness. However, texture can be varied to suit different appearance and functional uses. For example, a pebbly surface that breaks up a reflected image can be obtained for architectural applications. Similarly, a smooth, gritty surface can be produced for chalkboards that will take chalk evenly and erase easily. Also, interesting textural effects can be produced by

applying porcelain enamels to embossed or rigidized metal.

Color

A wide color selection has been developed in recent years. White and pastels are the colors most frequently specified today. Uniformity of all colors can be controlled closely, but slight variation in a few colors, such as the purples and scarlets, is to be expected.

Color Permanence

One of the outstanding features of porcelain enamels. Since the pigments used consist primarily of inorganic compounds, they are extremely stable after aging, and in the presence of ultraviolet and infrared radiation, heat oxidizing agents and corrosive fumes. Color permanence of porcelain enamels is attested by their use as physical color standards for the printing ink, paint, plastics and textile industries.

Cleanability

Depends on surface texture. A smooth, glossy enamel is easier to clean and affords less opportunity for dirt attachment than a rough enamel. No matter what the texture, the hardness and abrasion resistance of porcelain enamel permits the use of cleaning methods that might damage other coatings.

In addition to resisting most common agents, porcelain enamels are also highly resistant to radiological and biological contamination. Surface contamination can be removed quickly and easily by simple washing. Also, surfaces resist most common germicidal solutions and can be sterilized with live steam without damage.

2. Mechanical and physical properties

Adhesion

Good adhesion is produced by reaction and fusion of the enamel with the base metal at high temperatures. The bond has many characteristics of a true chemical bond, although its exact nature and mechanics of formation are not completely understood. Since moisture or rust cannot penetrate beneath the coating, it will not flake away from exposed edges or damaged areas.

Hardness

Depending on composition, hardness ranges from $3\frac{1}{2}$ to 6 on the Mohs scale, with most enamels for sheet iron falling in the range of 4 to $5\frac{1}{2}$. Comparable values on the Knoop scale range from 150 to 500; average value on the Sward scale is 100. As a rough approximation, typical enamels on sheet iron have about the same hardness as plate glass or the edge of a knife blade.

Conveyor screw *(right) is porcelain enameled to provide high abrasion resistance.*

Abrasion and Wear Resistance

Excellent resistance to abrasion and wear because of their high hardness and good lubricity. In general, abrasion resistance of enamels is about the same as that of plate glass. Enamels frequently provide better wear and abrasion resistance than metals. This is attested by their use on bunker and silo discharge chutes, coal chutes, water lubricated bearings, screw conveyors, work surfaces and chalkboards.

Lubricity

Glossy enamels have high lubricity or slipperiness, particularly when wet. Lubricity of porcelain enamels is particularly important in low friction applications, such as water-lubricated bearings where the enamel mates with rubber, and in promoting the flow of coal and other materials in chutes kept at a low angle of inclination. If desired, enamels can be specially formulated to have a high coefficient of friction. Such enamels are used on nonskid stairs for ships, shower stall bases and bathtub bottoms.

Impact Resistance

Like glass, porcelain enamel will fracture when abused. It is difficult to predict the impact resistance of an enamel, since it depends as much or more on the design of the part as on the properties of the enamel. However, an enamel can be surprisingly strong and flexible if used on a properly designed part. As a general rule, porcelain enamel will not fracture due to impact unless the base metal is permanently deformed. Because of its high compressive strength the enamel is rarely crushed at the point of impact.

Flexibility

Usually considered to be brittle and to have little flexibility. This impression probably stems from the

fact that heavy coatings applied to thick metal articles (such as bathtubs) tend to fracture when lightly bent.

However, thin enamels have very good flexibility and adhesion when applied to thin metals. For example, a 10-mil commercial sheet protected with two coats of porcelain enamel 5 mils thick is so flexible that it can be shipped in 12-in. dia coils without damage. In addition, experimental enamels applied at a thickness of 1.5 mils to steel sheet 4 mils thick have been deformed to a radius of 1.5 in. without damage.

Stiffening

Because of its low ductility and intimate bond, porcelain enamel increases base metal flexural strength. Thus, the enamel's stiffening effect can be used advantageously to reduce metal thickness in certain applications. Flexural strength of a flat enameled sheet is equal to that of an unenameled sheet of total thickness equal to the thickness of the steel base plus half the thickness of the porcelain enamel. The stiffening effect is more pronounced on lighter gages than on heavier gages of metal. Also, for metal coated on one side only, the effect is greater when the enamel is on the compression side of the beam.

Thickness

Can be applied in a wide range of thicknesses—from 1 mil or less to 1/8 in. or more. Optimum thickness depends on composition of the enamel and base metal, and on expected service conditions. In general, thinner coatings are more flexible and have greater resistance to fracture. Thicker coatings have better electrical properties and withstand abrasion and chemical attack for longer periods before penetration of the coating occurs.

Porcelain enamels usually consist of a base or ground coat 2 to 5 mils thick, and one or more cover coats, each 2 to 20 mils thick. Normally, a white cover coat should be at least 3 mils thick to produce satisfactory appearance and hide light scratches in the metal. Certain colors and textural effects can only be obtained with relatively thick coatings. However, purely functional coatings, such as high temperature protective coatings, are usually applied quite thin—as thin as 1 mil or less.

Thicknesses over 25 mils are not generally recommended for sheet metal parts because of warpage problems. Normally, heavy coatings are used on cast iron or steel plate whose rigidity resists deformation and reduces the danger of fracture. Such coatings are desirable to hide rough spots on the metal and to provide longer life.

Enamels for aluminum sheet are usually applied at a minimum thickness of 3 mils. However, thicknesses of 7 to 10 mils may be required for a specified appearance.

Thermal Expansion

Coefficient of thermal expansion is largely determined by chemical composition. Enamels can be formulated to meet most end uses and expansion coefficients can be varied from about 2.8 to 16×10^{-6} per deg F.

Being glass-like, porcelain enamel is much stronger in compression than in tension. Hence it is desirable to have the coefficient of expansion of the enamel lower than that of the base metal so that in cooling the enamel will be in compression, not tension. The amount of compressive stress allowed to develop must be controlled carefully; if it becomes too high fracture can occur at sharp radii.

Excessive compressive stress can increase warpage tendencies, particularly with thin metal coated on one side only, or having unequal enamel thicknesses on the two sides. Thus, residual compressive stresses should be low in such parts as appliance and architectural panels. On the other hand, enamel residual stresses should be kept high on parts subject to failure by thermal shock or bending.

Thermal Conductivity

Thermal conductivity values are reportedly in the range of 6 to 9 Btu/hr/sq ft/°F/in. Normally, porcelain enamels are applied so thin that there is only a very small temperature gradient through them.

3. Resistance to corrosion

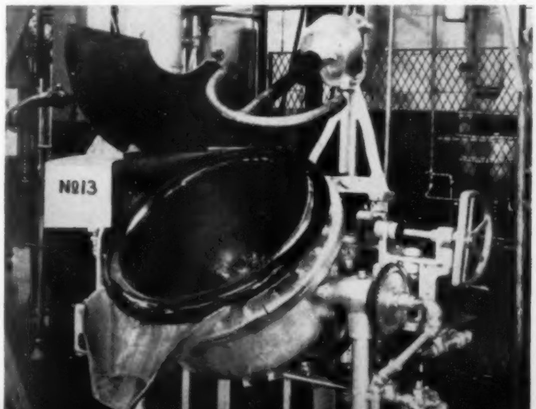
Acid Resistance

Varies widely depending on composition and, to some extent, the processing used. Special enamels can be formulated to resist almost any acid except hydrofluoric. However, the highest degree of acid resistance is obtained only by sacrificing other desirable properties. Actually, degree of attack by an acid solution appears to depend less on type of solution than on its pH.

Alkali Resistance

Practically all porcelain enamels are unaffected by

Chemical and food processing equipment *(below) are frequently coated with glass-like porcelain enamel to reduce contamination and improve corrosion resistance.* Pfaudler Co.



alkalis at room temperature. Special enamels can successfully resist hot solutions of the wide variety of alkali detergent washing solutions developed in recent years. They are completely dissolved in boiling concentrated caustic alkali, although it is highly unlikely they will ever encounter such a medium.

Alkali resistant porcelain enamels are not necessarily acid resistant, and vice versa. However, there are porcelain enamels available that resist both acids and alkalis.

Resistance to Other Chemicals

Completely resistant to attack by organic solvents, dyes, greases and oils. Enamels are not dissolved by these materials and do not absorb them. A few organic materials hydrolize on contact with moisture to form acid solutions that may attack some enamels. This problem can be overcome by specifying an acid resistant enamel.

Weather Resistance

Usually measured by the degree to which an enamel retains its original gloss and color. In general, acid resistant enamels have better weather resistance than non-acid resistant enamels. Thus, enamels exposed to weathering should be specified with not less than a Class A acid resistance rating.

Instances are known of porcelain enameled signs that are still in good condition after 50 years of exposure. Tests conducted by the National Bureau of Standards show that porcelain enamels of even the poorest weather resistance can protect metal from corrosion for 15 years outdoors. This conclusion does not apply to metal areas that had poor initial coverage or were mechanically damaged. Glossy, acid resistant enamels have shown no appreciable change in appearance after 15 years exposure. However, similar exposure changed the appearance of some matte and non-acid resistant enamels to an objectionable degree. Also, some types of highly pigmented red and yellow enamels have shown appreciable fading after a few years of weathering.

Water Resistance

All porcelain enamels are completely resistant to water at room temperature. Although most enamels will withstand boiling water for hours or days without damage, they will be slowly attacked when subjected to continuously changing hot water over a period of years. However, special porcelain enamels have been developed for storage tanks that will withstand continuous exposure to hot water for 10 to 20 years without damage.

Freezing and thawing in the presence of moisture will cause some porcelain enamels (and many other coatings) to spall or disintegrate. This can occur in "cold wall" refrigeration systems where wall temperature fluctuates above and below freezing. However, properly selected and processed porcelain enamels will withstand thousands of cycles of freezing in the presence of moisture without failing.

Salt Spray Resistance

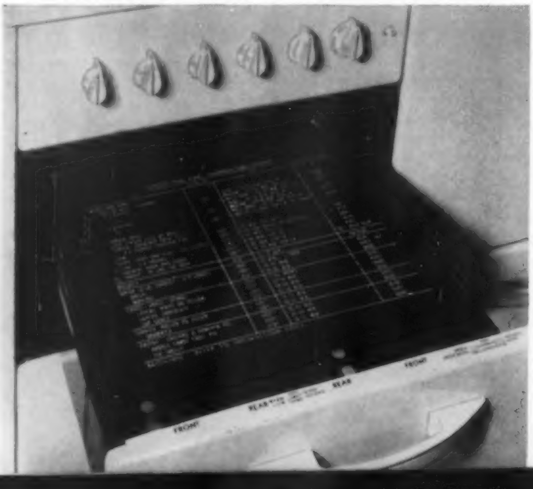
Many evaluations have shown that porcelain enamels with complete coverage will withstand the standard ASTM B117-57T salt spray test for days and even weeks without evidence of corrosion. In addition, experience has shown that porcelain enamels provide excellent service in applications involving salt air exposure or intermittent or continuous exposure to sea water.

Soil Corrosion Resistance

Standard method of testing is to bury test specimens in different types of soils for periods up to 10 years or more. It has been found that corrosiveness of a particular soil depends primarily on chemical composition of the ground water. Special porcelain enamels that are resistant to both acid and alkaline ground waters will protect buried metals for years without damage.

4. High temperature properties

Ovens *and similar appliances continue to be one of the most popular high temperature applications for porcelain enamel.*



Resistance to Corrosion and Oxidation

Porcelain enamels and ceramic coatings have long been noted for their ability to eliminate or appreciably reduce the oxidation of base metals. As a result they can reduce costs and improve performance in one or more of the following ways: 1) they may permit the use of less costly alloys without loss of properties, 2) they may extend base metal life, and 3) they may increase the metal's maximum operating temperature, thereby improving the efficiency of an operation.

The ability of porcelain enamels and ceramic coatings to prevent oxidation is largely due to the fact that the coatings themselves are fully oxidized and

do not undergo further oxidation at elevated temperatures. Also, they form an effective barrier to diffusion of oxygen. The protective ability of a porcelain enamel depends on the temperature at which it starts to deteriorate (i.e., about 400 °F below firing temperature). However, special ceramic coatings may be effective above the firing temperature and can protect metals from oxidation above 2000 F.

Porcelain enamels and ceramic coatings also resist the high temperature corrosive action of such media as sulfur dioxide and trioxide, lead bromide, and vanadium oxide, and prevent carbon gases from reacting with base metals. Their smoothness and hardness are also effective in reducing corrosion and erosion rates at high temperatures.

Thermal Stability

A measure of ability to withstand intermittent or prolonged heat without changing physical, chemical or appearance properties. The maximum temperature to which an enamel can be heated for extended periods is related to its firing temperature. In general, no damage will occur if it is heated to about 400 °F below its firing temperature. Since usual firing temperatures vary from 900 to 1700 F, the highest temperature at which an enamel can be subjected to prolonged heating varies from 500 to 1200 F or higher.

Thermal Shock Resistance

Thermal shock failure of a porcelain enamel is caused by rapid chilling of the surface. It manifests itself in a crack and occurs when the thermal gradient perpendicular to the surface is large enough to cause excessive shrinkage and tensile stress.

The two most important considerations are the enamel's thickness and its coefficient of thermal expansion—the latter as an indicator of thermal stress. It has been stated that thermal shock resistance of a porcelain enamel varies inversely as the cube of the thickness. Other things being equal, best thermal shock resistance is obtained with thin coatings—on the order of 5 mils or less. A high compressive stress in the enamel, produced by a low coefficient of thermal expansion, is also desirable.

Thermal shock resistance is also affected by the design and thickness of the part. Flexing of the metal due to localized thermal gradients parallel to the surface can produce bending stresses in the coating. Thus, any increase in the strength or rigidity of a part helps increase the enamel's resistance to thermal shock.

Emissivity

Porcelain enamels have high total emittance at high temperatures. Typical values are on the order of 0.95 at room temperature, falling to about 0.65 at 1500 F. The color of an enamel has practically no effect on total emittance at room temperature, but will have an effect at high temperatures. White enamels, for example, generally have lower emittance than black enamels or ground coats at high temperatures.

A typical white porcelain enamel has low spectral emittance at short wavelengths of about 0.2 to 0.5 μ. Spectral emittance increases as wavelength increases to about 5 μ, and remains high at all longer wavelengths. Values as high as 0.95 may be obtained at some wavelengths. A black enamel has appreciably higher spectral emittance than a white enamel at short wavelengths; they are about the same at wavelengths longer than about 5 μ.

5. Electrical properties

Dielectric Strength

Because of surface variations and bubbles that are usually present, porcelain enamel will vary from point to point. Thus, dielectric strength of ordinary enamels will range from about 250 to over 1400 v per mil. However, bubble-free coatings can be produced which have uniformly high voltage breakdown.

Volume Resistivity

Varies from 10^{13} to 10^{16} ohm-cm at room temperature. Volume resistivity will decrease markedly with an increase in temperature. In fact, porcelain enamel actually becomes a fairly good electrical conductor at and above the firing temperature.

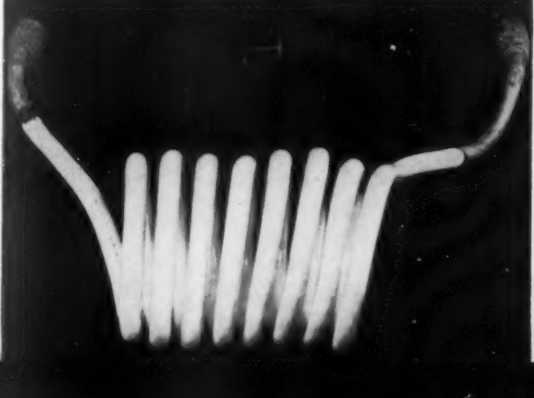
Dielectric Constant

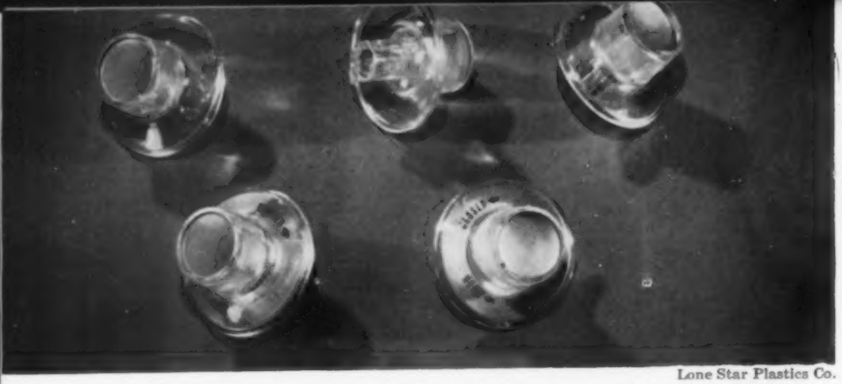
At 500 cps and room temperature it is in the range of 6 to 12. A sharp increase in values can be expected at temperatures above 250 to 300 F.

Dissipation Factor

At 400 cps and room temperature it is about 1 or 2. Much higher values occur at temperatures above about 200 F.

Coated copper coil *of induction heater illustrates good electrical insulation provided by porcelain enamel.*
Chicago Vitreous Corp.





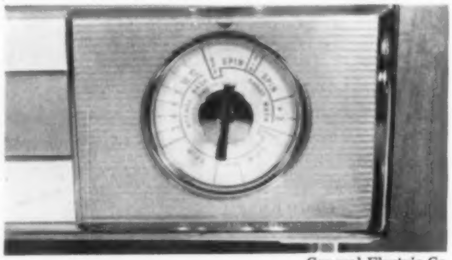
Lone Star Plastics Co.

Air conditioner control knobs—*Clarity, heat resistance, strength and attractiveness were the reasons cited by Lone Star Plastics for selection of the copolymer for knobs for a Mathes window air-conditioning unit.*

St. Charles Mfg. Co.

Tracks for sliding doors—*Reproducible quality, fast assembly and accurate dimensions caused selection of the copolymer for tracks for sliding glass doors on St. Charles Mfg.'s Midway kitchen unit. Extruded by Perflex Plastics, the tracks also offer quiet operation, and excellent abrasion resistance according to St. Charles' 200,000 cycle abrasion test against glass.*

Washer dial face—*Replacing high heat, general purpose polystyrene, the copolymer material provides additional toughness and reduces residual strains in the finished dial face, according to G. E.-Louisville. The dial is molded for G. E. by Madan Plastic.*



General Electric Co

Low Cost, Transparent Plastic

Styrene-Acrylic Copolymer Has Good Weatherability

■ In the past year a new copolymer of styrene and methyl methacrylate has been tapping the market for a lower cost molded acrylic (polymethyl methacrylate). In some cases, where its superior performance justifies increased cost, it has replaced G.P. (general purpose) polystyrene. But selling at more than twice the cost of polystyrene, such occasions should be rare.

From the engineered applications that have developed, as well as those under serious evaluation, Dow Chemical Co. feels that the future of its new material, called Zerlon, is assured.

Priced at 49¢ per lb—substantially higher than the 21.5¢ polystyrenes, but lower than the 55¢ acrylics—the copolymer has crystal clarity. Light and weather stability are substantially better than that of polystyrene, and approach that of acrylics. Heat resistance is superior to both.

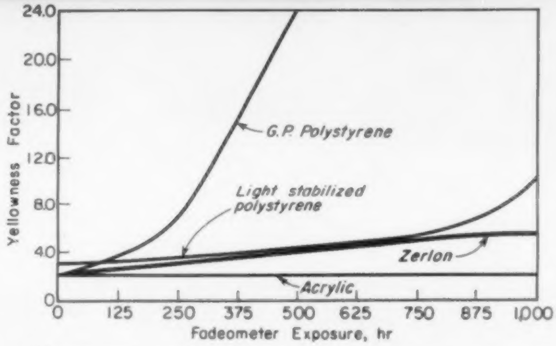
The importance of cost varies with the application. Actually, differential in cost on a volume basis may not appear large. For example, the new copolymer costs 2.1¢ per cu in., compared with 2.4¢ per cu in. for polymethyl methacrylate. But at these costs a cubic foot of the coplymer costs $36.28, while a cubic foot of acrylic costs $41.47. In large volume production such a difference can be critical.

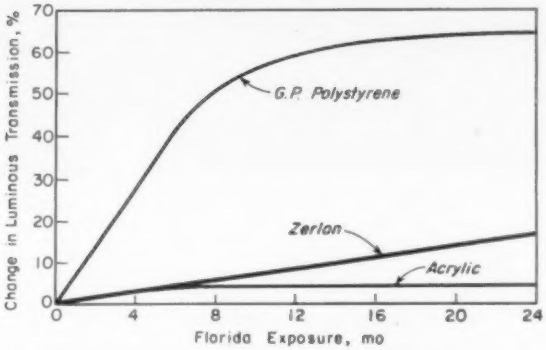
Light and weather resistance

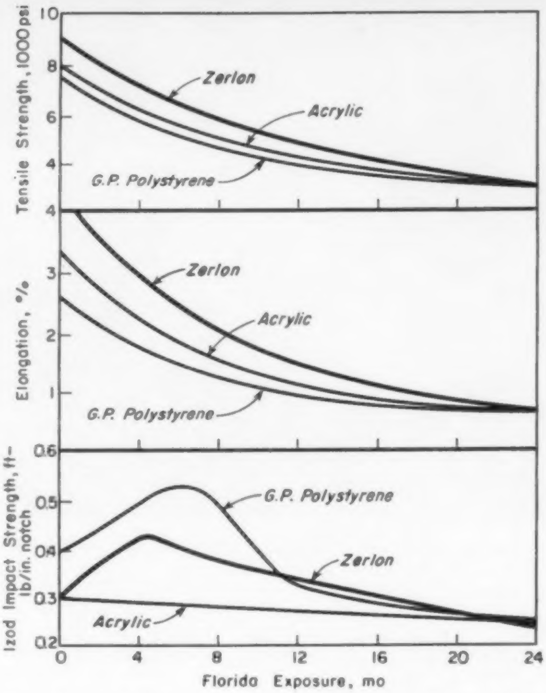
Materials costs must be considered in relation to performance of the part in service. Evaluating such properties as light and weather resistance and predicting performance on the basis of this evaluation is difficult at best. But recently developed data do indicate the relative stability of the copolymer material. In all the tests made, the copolymer material falls between polystyrene and acrylic in light and weather resistance, but much closer to that of acrylics.

In determining light and weather resistance, changes in color, light transmission and mechanical properties are pertinent. Fig 1 shows the effect of 1000 hr Fadeometer exposure on yellowness factor of the new material, compared with that of G. P. and light-stabilized polystyrene and polymethyl methacrylate. Zerlon yellows slightly more than the acrylic, and is roughly comparable to the light-stabilized polystyrene up to about 750 hr exposure, after which yellowness factor of the stabilized polystyrene increases relatively rapidly. Fig 2 shows percentage change in luminous transmission of the copolymer after 2 years of Florida exposure

Fig 3 shows effect of two-year outdoor exposure in Florida on tensile strength, elongation and impact strength of the new copolymer material. Tensile strength







***1**—Fadeometer exposure (upper left) compares yellowness factor (T[illegible]—T[illegible] × 100) of new copolymer with G. P. and light-stabilized polystyrene and polymethyl methacrylate. **2**—Effect of 2-year exposure in Florida on light transmission of copolymer compared with G. P. polystyrene and polymethyl methacrylate (lower left). **3**—Effect of 2-year Florida exposure on tensile strength, elongation and impact strength (right).*

and elongation, though initially slightly higher than those of acrylic and general purpose polystyrene, decrease until they are comparable. Impact strength increases initially, though not as much as that of general purpose polystyrene, then decreases to approximately that of acrylic after two years exposure.

Other properties

The accompanying table compares physical properties of the new copolymer material with those of polystyrene and polymethyl methacrylate both in injection molded form and as extruded sheet.

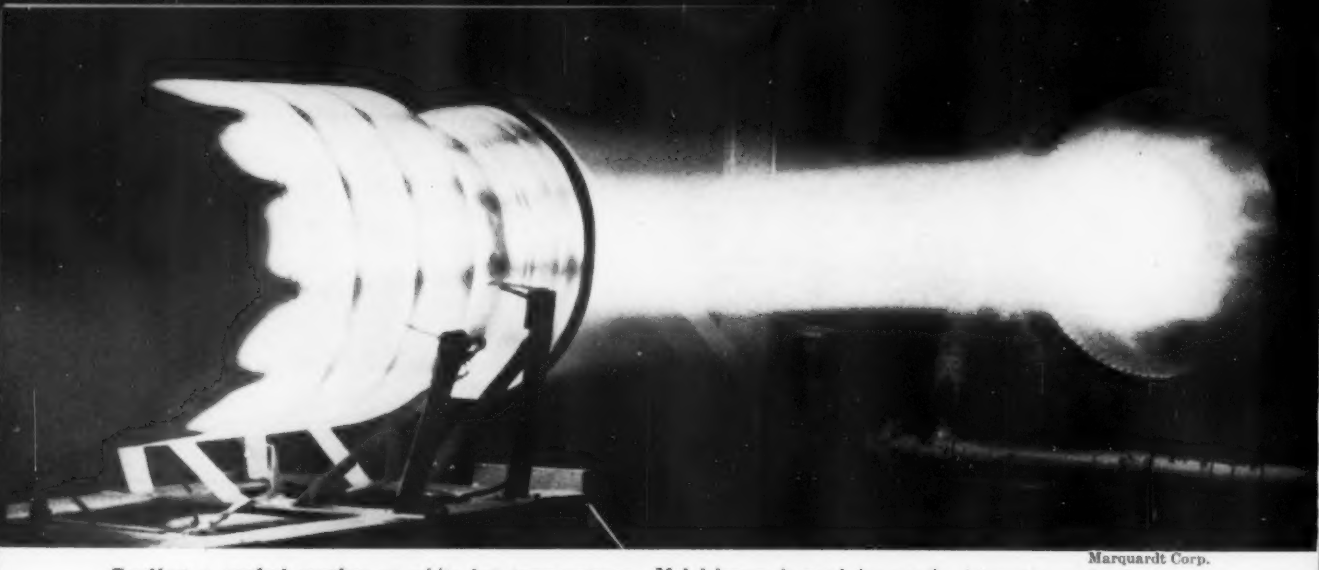
For the types of applications for which the material seems best suited, probably the most significant differences shown in the table are 1) heat distortion temperature, which is higher than both general purpose polystyrene and polymethyl methacrylate, 2) luminous transmission, which is higher than that of general purpose polystyrene, and 3) the marginal improvement in mechanical strengths over polystyrene.

Chemical resistance data are limited. The material is reported to have excellent resistance to 30% sulfuric acid, saturated solution of sodium hydroxide, diethylene glycol, mineral oils, and butter; good resistance to detergents and bleaches, and orange juice; only fair resistance to gasoline, and poor resistance to concentrated sulfuric acid and alcohols.

TYPICAL COMPARATIVE PROPERTIES OF STYRENE-ACRYLIC COPOLYMER[a]

	General Purpose Polystyrene	Copolymer (Zerlon)	Polymethylmethacrylate
Specific Gravity	1.05-1.07	**1.14**	1.18-1.19
Luminous Transmission, %	88-90	**>91**	>92
Shrinkage, in./in.	0.002-0.006	**0.002-0.006**	0.002-0.007
Heat Distortion Temp (264 psi), F	175-190	**205**	166-202
Rockwell Hardness	M68-80	**M78**	M80-103
Tensile Strength, 1000 psi			
Injection Molded	6-7	**9**	8-10.5
Extruded Sheet			
MD	4.4	**8.6**	7.5
CMD	5.9	**8.3**	7.8
Elongation, %			
Injection Molded	1.5-2.5	**4-5**	3-5
Extruded Sheet			
MD	1.0	**3.1**	2.7
CMD	1.4	**2.6**	2.7
Flexural Strength, 1000 psi			
Injection Molded	12-15	**17.6**	15-16
Extruded Sheet			
MD	10.7	**13.6**	13.3
CMD	10.0	**13.4**	13.3
Izod Impact Str, ft-lb/in. notch			
Injection Molded	0.3-0.6	**0.4**	0.3-0.5
Extruded Sheet			
MD	0.3	**0.3**	0.3
CMD	0.3	**0.3**	0.3

[a]All data from Dow Chemical Co.; properties for polymethyl methacrylate from published data.



Marquardt Corp.

***Testing a rocket engine** at white hot temperatures. Molybdenum is used for nozzle, jetavator, and other parts of a solid propellant rocket engine.*

An Up-To-Date Report on Molybdenum Metal

by J. Z. Briggs and R. R. Freeman, *Climax Molybdenum Co.**

Fabrication, protection, mechanical properties and applications of an important refractory metal.

■ The metal molybdenum has properties of great engineering interest. Progress in both arc casting and powder metallurgy have removed some of the size limitations that formerly restricted its use; ingots up to 12 in. dia are now being produced and converted to billets, forgings, sheets, tubes and bars. And fabricating experience gained over the past few years has shown that, with suitable precautions, parts can be produced on conventional equipment.

The major properties that make molybdenum useful can be briefly pointed up as follows:

▸ With a melting point almost 2000 F higher than that of iron, molybdenum can be used at temperatures above the softening point of most metals. Above about 1600 F, the useful strength of molybdenum exceeds that of the superalloys.

▸ At 2000 F, modulus of elasticity is as great as that of iron at room temperature.

▸ Electrical conductivity is good—about one-third that of copper.

▸ Low coefficient of thermal expansion combined with high thermal conductivity impart excellent thermal shock resistance to molybdenum. In addition, its specific heat value is low.

Working molybdenum: latest information

Five general characteristics of metallic molybdenum you need to know for all working operations:

1. Mechanical properties of unalloyed molybdenum depend, to a large degree, on the amount of warm working (work done below the recrystallization temperature). Optimum ductility is obtained when reduction is at least 50%.

2. Fully recrystallized molybdenum, because of its lower mechanical properties, flows more easily in working than molybdenum given other prior treatments. Because of poor bend and impact characteristics, however, it should not normally be specified for parts which must be fabricated by bending or deep drawing. Fully recrystallized molybdenum should be used when: 1) mechanical properties after working are not important, and 2) subsequent processing will include sufficient warm work to produce the necessary properties.

3. Relative to its high melting and recrystallization temperatures, molybdenum is much "colder" at room temperature than steel. Toughness and ductility of molybdenum are higher at temperatures above room temperature (400 F, for example). Except for fine wire and sheet, at least a moderate amount of heating is recommended for all working operations.

4. Molybdenum, because of its high thermal conductivity and low specific heat, heats and cools much more rapidly than steel.

5. The high strength of molybdenum at elevated temperatures, relative to other common metals requires the use of more powerful equipment for a given amount of work.

Heating for working

Up to 700 F—Except in very small sizes, molybdenum can be

* Abstracted from the booklet "Molybdenum Metal" recently published.

heated to approximately 700 F in air, on a gas or electric hot plate, without excessive oxidation (if the heating time is not too long). Infrared lamps or oxyacetylene torches can also be used for thinner sections. Temperature crayons should be used with these heating methods. Heating molybdenum sheet in oil is preferred for deep drawing applications.

Over 700 F—A controlled atmosphere furnace, salt bath or induction heating should be used. The controlled atmosphere may consist of a vacuum, inert gas, or a slightly reducing mixture of gases. Cracked ammonia should not be used since the nitrogen in the ammonia will diffuse into the molybdenum and affect formability. To prevent the molybdenum from coming in contact with slag or scale on the furnace bottom, a stainless steel hearth plate should be used.

Molybdenum reaches temperature four times faster than carbon steel. No holding at temperature is necessary with small sizes.

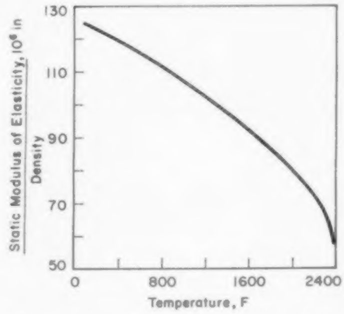
Forging

Swaging, hammer and press forging are performed conventionally. Molybdenum exhibits flow tendencies similar to those of steel, although much higher impact velocities are required before plastic flow begins. Once the forging operation is begun, it should be continued until the operation is completed. Fig 1 on next page shows forged molybdenum parts intended for service in a highly corrosive environment.

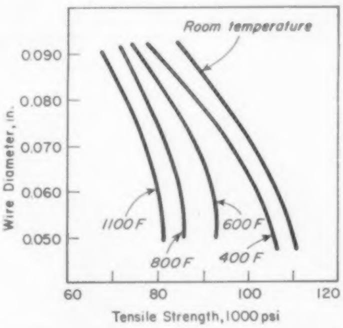
Choose dies carefully—It is difficult to make molybdenum forgings on flat dies both because of the slippery oxide formed on the metal and because of its tendency to "go diamond" (assume a diamond shape that is difficult to bring back to the desired round, square or rectangular form). These problems are reduced by using shaped dies or forging in an inert atmosphere.

Temperatures, reductions—Most forging operations are conducted from maximum temperatures of 2150 to 2350 F down to a mini-

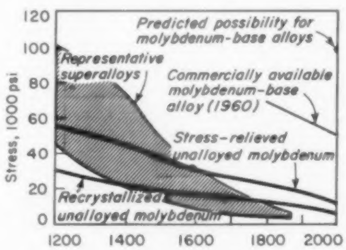
Mechanical Properties—Here Are Some of the Newest Data on Unalloyed Molybdenum.



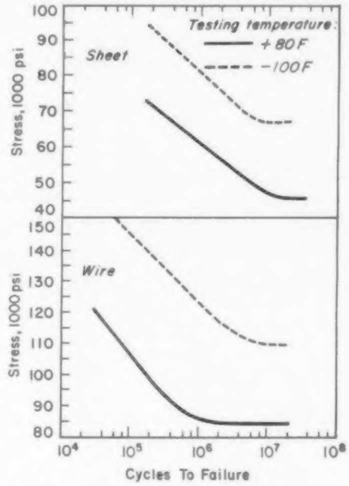
Stiffness-weight ratio *of arc cast molybdenum as affected by temperature.*



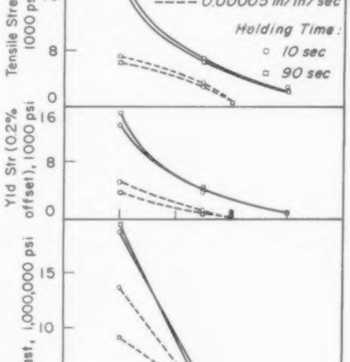
Tensile strength *of molybdenum wire as affected by temperature and diameter.*



Rupture strength *of unalloyed molybdenum and molybdenum-base alloys as compared to values obtainable with representative superalloys.*



Low temperature fatigue *properties of unalloyed molybdenum made by powder metallurgy.*



Short time tensile strength *of unalloyed, arc cast molybdenum as affected by temperature.*

COMPARISON OF COATINGS

	Continuous Oxidation Life, Hr[a]										
Operating Temp, F ➡	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3500
Electroplated Cr-Ni (1 mil Cr, 7 mils Ni)	—	1000	350	100	>1	—	—	—	—	—	—
Metallized Al-Cr-Si (5-10 mils)	—	>500	>500	~100	350	>4	4[b]	4[b]	—	—	—
Metallized Ni-Cr-B (5-10 mils)	—	>500	>500	<25	<1	—	—	—	—	—	—
Metallized Ni-Si-B (5-10 mils)	—	>500	1000	<10	<1	—	—	—	—	—	—
Metallized LM-5 (5 mils)	—	—	—	—	500	—	—	—	—	—	≪1
Vapor Deposited $MoSi_2$ (1-3 mils)	6500	—	3700	—	2000	—	—	100 1415[c]	77	28	18
Vapor Deposited Chromalloy W-2 (1-3 mils)	—	—	7200	—	500	—	—	>¼	—	>1 min	—
Clad Ni-Base (3 mils)	—	>2000	250	—	—	—	—	—	—	—	—
ZrO_2 Frit (10 mils)	~70	—	—	—	>½				—	¾	—
Cr Frit (10 mils)	~200	~4000	—	—	~5	~5	~5	~1	—	—	—

Source: Bartlett, Ogden and Jaffee, "Coatings For Protecting Molybdenum From Oxidation at Elevated Temperature," *DMIC Rpt 109*, Mar 6, '59.
[a]May include occasional cycling for examination. [b]After extensive prediffusion. [c]Boride modification.
[d]Within part-design limitations for process.

mum temperature of 1700 F.

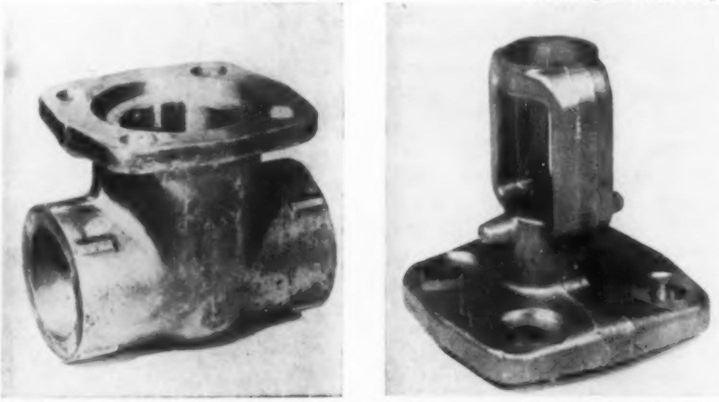
Optimum properties are obtained by controlling forging and reheating temperatures to provide at least 50% reduction in the warm working range. As each successive forging operation is completed, heating temperatures must be lowered (since increasing amounts of warm work lower the recrystallization temperature). Reductions of as much as 90% have been made without difficulty. When larger reductions are made in the lower temperature range, intermediate recrystallization treatments may be necessary.

Large or complex forgings that have received considerable work should be stress relieved in the temperature range 1600–1800 F as soon as possible after forging.

Spinning

Spinning and power roll forming are satisfactory means of producing molybdenum parts. No change in customary procedures is needed except for heating the stock. Light gages (under 0.020 in.) can be spun and formed at room temperature, but it is better practice to heat both the work and tools. Heavier sheet and plate must be heated according to the recommendations in Fig 2 (which serves as a guide for most molybdenum forming operations).

New England Valve Corp.



1—*Valve body, bonnet and yoke designed for use in hot sulfuric acid were forged from unalloyed, arc cast molybdenum. (Approximately full size.)*

It is usually desirable to supply heat continually during spinning or roll forming; oxyacetylene torches are the most convenient way of doing this. Cross-rolled sheet is generally needed to avoid directionality. Two extremes in spun part size are shown in Fig 3.

Applying molybdenum

The criteria for choosing between molybdenum and molybdenum-base alloys are these:

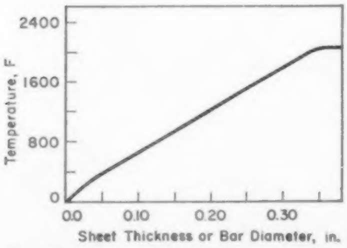
▶ If the application depends on physical or chemical properties, unalloyed molybdenum or molybdenum-base materials with high tungsten content should be considered. Low alloy molybdenum-base alloys have approximately the same physical and chemical properties as the unalloyed metal.

▶ If the application depends on mechanical properties, use molybdenum-base alloys for higher creep and rupture strengths. The higher recrystallization temperatures of the alloys allows the advantages of work hardening to be retained at higher service temperatures.

Many of the industrial applica-

Probable Reliability Rating[d]	Thermal Shock Resistance: Cycles[e]	Thermal Shock Resistance: Probable Rating	Hot Ductility, or Resistance to Failure During . . . Ballistic Impact[g]	Hot Ductility, or Resistance to Failure During . . . Stress-Induced Deformation[g]	Temperature for Self-Healing, F	Hot Erosion Resistance: Time in Alumina Blast, min	Hot Erosion Resistance: Probable Rating	Ease of Protecting Corners, Recesses, etc.	Strength Retention of Molybdenum During Application
Fair	~140	Fair	Good	Fair	—	95	Good	Fair	Good
Good	~500	Good	Poor	Fair	>2600	25	Fair	Poor	Good
Good	~200	Fair	Good	Excellent	—	60	Fair	Poor	Good
Good	~100	Fair	Good	Excellent	—	50	Fair	Poor	Good
Good (?)	Several[f]	Fair (?)	—	Excellent	2000	—	Good (?)	Poor	Good
Excellent	>100	Good	—	Fair	>2800	—	Good	Good	Poor
Good (?)	>30	Good	—	Good	(Some)	—	Good	Good	Fair
Good	~100	Fair	Good	Good	—	70	Fair	Poor	Good
Fair	>10	Good	—	—	1800 (?)	—	Good (?)	Fair	Fair
Fair	>60	Good	—	Fair	1800	—	Good (?)	Fair	Poor

[e]In the room temperature to 400 F and 1600 to 3000 F ranges, usually less than 1 min for heating or cooling.
[f]After diffusion treatment. [g]At ambient temperature.



2—*Working temperature of unalloyed molybdenum correlated with thickness of part. This plot should serve as a guide in shearing, spinning, stamping or punching, Floturning (power roll forming), Hydroforming, bending, stretch forming, and deep drawing. For sawing with a handsaw, the material should be warmed according to thickness up to about 400 F max. The plot does not apply to welded sections: up to ⅛ in., welded sections should be heated to 1800-2000 F; above ⅛ in., up to 2350 F.*

Newark Spinning and Stamping Co.

3—*Two spinnings made by regular lathe spinning. The large spinning was spun from arc cast sheet, 0.10 x 20 x 20 in. The smaller one (circled) was spun from 0.010-in. thick sheet made by powder metallurgy.*

tions of molybdenum are listed below:

Electronic and electrical industries
- Incandescent and fluorescent lamps
- Electronic tubes
- Electric furnaces
- Electrical contacts and electrodes
- Brushes
- Miniature dry cells
- Miniature electronic transducers
- Transistors and rectifiers

Missile and aircraft industries
- Missiles and rockets
- Jet engines
- Air frames
- Accessories
- Rocket test sleds

Metalworking industries
- Die casting dies and cores
- Hot work tools
- Boring bars, tool shanks and grinding quills
- Chill plates and fixtures
- Resistance welding electrodes and dies
- Cladding
- Truing grinding wheels
- Molds
- Thermocouples
- Molybdenum-impregnated plastic metalworking dies

Nuclear energy industry

Chemical industry

Glass industry

Metallizing industry

Marbon Chemical

Naugatuck Chemical

For good-looking parts . . .

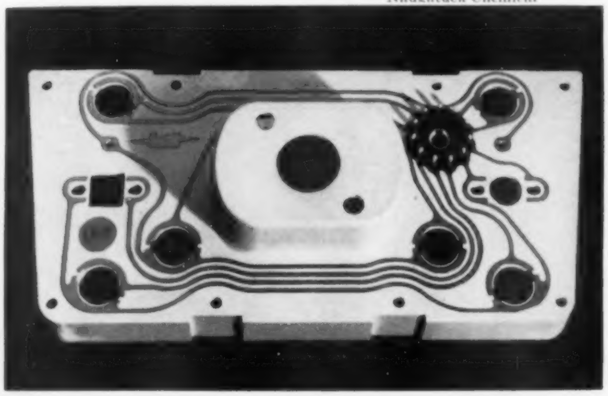
Call director *(left) produced by Western Electric. Appearance, cost, toughness, light weight and stain resistance were important factors.* **Auto parts** *(right) for a five-passenger Fiat 2100 include a one-piece dashboard molding.*

. . . or strictly functional parts

Pump impellers *(left) made by Barnes Mfg. Co. use ABS for its combination of chemical resistance, toughness and low cost.* **Printed circuit base** *(right) molded by Ucinite Co. calls for balance of toughness, wide service temperature range, corrosion resistance and electrical insulating characteristics.*

Naugatuck Chemical

Naugatuck Chemical



ABS Plastics Are Low Cost, Tough, Resistant, Moldable

by Malcolm W. Riley, *Associate Editor, Materials in Design Engineering*

■ As of January this year Western Electric specifications for colored telephone handsets call for ABS plastics—another feather in the cap of these tough, strong thermoplastics. With the relatively recent development of heat resistant, high strength grades, and a medium impact nylon-like grade, ABS resins provide the diversity required to class them as a family of plastics in their own right—and quite distinct from the modified polystyrenes.

Briefly, the materials provide a balanced combination of mechanical toughness, wide permissible service temperature range (−40 to as high as 200 to 230 F), excellent resistance to chemicals and weathering, good electrical insulating properties, and good moldability. Grades are available for injection molding, extrusion and calendering. Topping off these properties is a cost of 50-60¢ per lb (about 2¢ per cu in.)—higher than polystyrene, slightly lower than cellulose acetate butyrate and propionate, substantially lower than nylon, acetal and polycarbonate.

Types available

There are two major producers of ABS materials, each supplying a variety of generally competitive grades: Marbon Chemical Co., with Cycolac; U.S. Rubber Co., with Kralastic compounds from

its Naugatuck Chemical Div., and Royalite thermoforming sheet from its Footwear and General Products Div. B. F. Goodrich Chemical Co. also produces an ABS: Polyblend 89001.

ABS materials can be generically classified into five major types as shown in the table on p 110:

1. *Medium impact* — A hard, rigid, tough material used for appearance parts which must have high strength, good fatigue resistance, surface hardness and gloss.

2. *High impact*—Used for similar applications, but where additional impact strength is required at some sacrifice in rigidity and hardness.

3. *Extra-high impact*—Has highest room temperature impact resistance, with a further decrease in rigidity, strength and hardness.

4. *Low temperature impact*—Tailored for high impact strength at temperatures down to −40 F; strength, rigidity and heat resistance again suffer.

5. *Heat resistant, high strength*—Provides maximum heat resistance (continuous use temperature of about 200 F; 264 psi heat distortion temperature of about 205-230 F, depending on molding conditions, etc.), with impact strength about comparable to that of high impact grades, but higher tensile and flexural strengths, modulus and hardness.

How ABS materials compare

With the inherent variability of plastics materials, and the limited amount of practical design information available, one of the most useful ways of initially evaluating a plastic is to compare it with other plastics. In so doing, remember that the comparisons given here are based on standard ASTM test results, and that such comparisons should only be used for initial screening.

The plastics materials most competitive with ABS resins can be conveniently grouped into two classifications:

1. Comparable or superior performance. These are the materials that ABS resins most closely resemble in properties and performance, but which may be substantially higher in cost.

2. Comparable or lower cost. These are the materials that are similar or lower in cost than ABS, but have certain properties approaching those of ABS.

The importance of cost varies. In some cases, cost is relatively unimportant compared with performance; in others, cost is primary and performance can be compromised. The table on the next page groups three materials competitive in performance and two materials competitive in cost. (For more comparisons see "Impact Thermoplastics: Which One to Use," M/DE, Nov '59, p 123.)

Performance comparison

On a strictly performance basis, the materials most competitive with ABS resins are probably acetal (Du Pont's Delrin), nylon, and polycarbonate (GE's Lexan). In the following discussions, remember that comparisons are made between the other materials and specific types of ABS—in most cases the medium impact grade. The comparisons may not be valid for all grades of ABS.

Acetal—On a performance basis, acetal is probably the material most competitive with ABS resins, but primarily with the medium impact grades. Compared with this grade of ABS, acetal has comparable impact strength—better at lower temperatures. It is slightly stronger, harder, and has roughly comparable rigidity.

Available long-term data indicate that creep resistance of medium impact ABS is superior to that of acetal. Consequently, acetal's apparent modulus (which takes into account deformation with time) falls off more rapidly with long-term loading than does that of medium impact ABS.

Acetal has exceptionally high fatigue strength. Fatigue data on ABS materials are unavailable. The history of use of ABS materials in such applications as luggage and shoe heels indicates that some types of ABS have good fatigue life.

At temperatures up to about 200 F, flexural modulus of medium impact ABS is superior to that of acetal. Above 200 F, where medium impact ABS's modulus is negligible, acetal is superior (at 300 F acetal still has a modulus of about 50,000 psi).

Grades of ABS other than medium impact have much higher impact strengths than acetal, but substantially lower strength, rigidity and hardness. With the exception of *heat resistant* ABS, other grades also have lower heat resistance.

Materials cost of acetal is over twice that of ABS; acetal costs about 4.5¢ per cu in. (based on a recently announced volume price of 88¢ per lb); ABS costs about 2¢ per cu in., based on a cost of 50-60¢ per lb (price differs with grade).

Nylon—Comparable in cost with acetal on a volume basis, nylon also can be compared most directly with the medium impact grade of ABS. One difference to be pointed out immediately is the low moisture absorption of ABS materials, compared with nylon's well-known moisture sensitivity. Although many data are available for nylon, making it possible to design around this characteristic, it is necessary to make allowances for changes in both dimensions and properties with changes in moisture content. For comparison purposes here, a type 6/6 nylon (Zytel 101) is used. Properties given are for equilibrium moisture content in air (2.5%).

Compared with medium impact ABS, nylon has comparable impact and tensile yield strengths, and elongation is substantially higher. Flexural modulus and hardness are lower. Creep is higher; consequently apparent modulus falls off more rapidly than for medium impact ABS.

Since nylon is a crystalline material, its heat resistance is more sensitive to magnitude of stress than is the case with amorphous materials such as ABS. However,

Type of ABS Resin ➡	ASTM	Medium Impact[e]	High Impact[f]	Extra High Impact[g]	Low Temperature Impact[h]	Heat Resistant[i]
MECHANICAL PROPERTIES						
Izod Impact Str, ft-lb/in. notch[a]						
At 73 F	D256	1.5	3-6	5-9	5-9	3.0-6.0
At 32 F	D256	0.7	1.5	1.8-3.0	5-6	2.0-2.5
At −40 F	D256	0.4	0.4-1.0	0.6-2.0	1.5-3.5	0.3-1.0
Tensile Strength, 1000 psi[b]	D638	8.8	5-6.7	5.1-5.5	3-4	7.5-8
Ultimate Elongation	D638	20	—	—	—	—
Tensile Yield Strength, 1000 psi	D638	8.8	5-5.5	5.1-5.5	3-4	7.5-8
Tensile Modulus of Elasticity, 10^5 psi	D638	4.0	2.9	2-2.1	1.0-2.6	3.5
Flexural Strength, 1000 psi	D790	13.5	7.5-10	7.6-8	3.5-6.5	12
Flexural Modulus of Elasticity, 10^5 psi	D790	4.5	2.5-3.2	2.2-2.5	1.7-2.8	3.5-3.7
Compressive Strength, 1000 psi	D695	11	5.8-8.3	5.9-6.4	2.5-5.6	10
Rockwell Hardness	D785	R118	R92-105	R80-96	R62-88	R108-116
Deformation Under Load (122 F, 2000 psi), %	D621	0.5	0.8	1.4	—	0.4
PHYSICAL PROPERTIES						
Specific Gravity[c]		1.07	1.04	1.02-1.06	1.02	1.06-1.08
Mean Density, lb/cu in.		0.039	0.037	0.038	0.038	0.039
Heat Distortion Temp, F[d]						
66 Psi	D648	215	213	207-208	209	220-240
264 Psi	D648	200-230	185-198	187-196	172-185	205-230
Water Absorption (24 hr), %	D570	0.3	0.2	0.2-0.3	0.2	0.2
Coef of Ther Exp, 10^{-5} per °F	D696	3.2	5.5-5.6	5.5-7.3	4.8-5.5	3.8-4.6
Ther Cond, Btu/hr/sq ft/°F/in.	C177	1.8	1.5-2	1.5-2.1	1.3-2.3	1.8-2.5
Flammability (>0.050 in. thick), ipm	D635	1.3	1.3	1.3	1.3	1.3
ELECTRICAL PROPERTIES						
Dielec Str (short time), v/mil	D149	385	350-400	300-315	385-400	360-400
Volume Resistivity, ohm-cm	D257	$>2.7 \times 10^{16}$	$1\text{-}8 \times 10^{13}$	$0.5\text{-}8 \times 10^{13}$	$1.3\text{-}8 \times 10^{13}$	$8\text{-}>10 \times 10^{13}$
Dielectric Constant						
60 Cps	D150	3.1	2.9-4.2	2.9-4.8	3.7	2.7-3.5
10^3 Cps	D150	3.1	2.9-4.2	2.9-4.5	2.7-3.5	2.7-3.4
10^6 Cps	D150	3.0	2.4-3.6	2.8-4.1	2.8-3.5	2.8-3.2
Dissipation Factor						
60 Cps	D150	0.004	0.009-0.015	0.011-0.021	0.011-0.073	0.034
10^3 Cps	D150	0.005	0.002	0.002	0.002-0.008	0.012
10^6 Cps	D150	0.010	0.026	0.018-0.026	0.018-0.020	0.021
Arc Resistance, sec	D618	70-80	70-80	70-80	70-80	70-80
COST						
Cents per Cu In.		1.9-2.3				
Cents per Lb.		50-60				

[a] ⅛-in. specimens.
[b] Tensile and yield strengths given for ABS are the same, since ultimate failure occurs at a stress lower than yield point; see stress-strain curves.
[c] For ABS, values are for natural color; colored compounds will vary depending on pigment used.
[d] For ABS, values cover range obtained on both injection and compression molded specimens. Highest values are generally for compression molded specimens, since molding procedure produces a degree of annealing; values may be 10-20 °F lower.
[e] General range obtainable in Kralastic MM.
[f] General range obtainable in Kralastic F and MH, and Cycolac T.
[g] General range obtainable in Kralastic B and MV, and Cycolac H and L.
[h] General range obtainable in Kralastic L and J, and Cycolac LT.

under low stress conditions nylon is usable at substantially higher temperatures than ABS; conversely, at higher stresses, its heat resistance is lower than that of medium impact ABS. In general, nylon has a higher degree of heat resistance than ABS. For example, although flexural modulus of medium impact ABS is superior to that of nylon at temperatures up to about 200 F, at 250 F medium impact ABS has a negligible modulus, while nylon has a modulus of about 50,000 psi.

Grades of ABS other than medium impact types have much higher impact strengths than nylon, are generally lower in tensile strength, and are higher in flexural modulus.

Other important attributes of nylon are its lower frictional and wear qualities, and its self-extinguishing characteristics which permit wider and more direct use of its electrical insulating characteristics.

Polycarbonate—The most expensive of the materials shown (4.7-6.5¢ per cu in. based on anticipated commercial price of $1.10-$1.50 per lb; 11¢ per cu in. based on semi-commercial introductory price), polycarbonates are premium materials with premium properties.

Polycarbonates have substantially higher impact strengths

WITH OTHER MATERIALS

	Acetal[j]	Nylon[k]	Polycarbonate[m]	Modified Polystyrene	
				Medium to High Impact	Extra High Impact
	1.4	1.5-2.0	12-16	0.6-3.0	6-9
	1.3	—	—	—	—
	1.2	0.5	1.5	0.2	0.3-1.3
	10	8.6-11.2	9-10.5	3.5-6.8	3.0-4.5
	15	200-300	60-100	5-35	30-40
	10	8.5-9.0	8-9	—	—
	—	2.1	3.2	3.0-4.5	2.5-2.8
	14	No break	11-13	No break	No break
	4.1	1.8	3.8	3-5	2.5-3.0
	—	—	11	—	—
	R120	R108	R118	M15-80	—
	0.5	1.4[l]	0.3[n]	—	—
	1.43	1.14[l]	1.2	1.04-1.08	1.05
	0.052	0.041[l]	0.043	0.038	0.038
	338	360-390[l]	283-293	—	182-185
	212	150-170[l]	280-290	155-190	155-180
	0.12	1.5	0.35	0.04-0.08	0.05-0.20
	4.5	5.5[l]	3.9	3.3-4.7	4.2-5.6
	1.6	1.7	1.3	0.3-0.9	0.3-0.9
	1.1	Self-ext	Self-ext	0.5-2.0	0.5-2.0
	500	385[l]	400	>450	300-650
	5-6 x 10^{14}	4.5 x 10^{13}[l]	2.1 x 10^{16}	10^{14}-10^{16}	10^{12}-10^{17}
	3.7	7.6	3.2	2.5-2.7[o]	2.5-4.0
	3.7	6.4	—	—	2.5-4.0
	3.7	3.6	3.0	—	2.5-4.0
	0.004	0.014[l]	0.009	0.0007-0.008	0.003-0.14
	0.004	0.02	—	0.001-0.010	0.003-0.16
	0.004	0.04	0.010	0.001-0.010	0.003-0.16
	129	—	—	—	—
	4.5	4.0	4.7-6.5[o]	1.2-1.7	
	88	98	100-150	25-40	

[i]General range obtainable in Kralastic HTHT and Cycolac C.
[j]Du Pont's Delrin.
[k]Values are for type 6/6 nylon (e.g., Zytel 101) at equilibrium moisture in air (2.5%), except where noted.
[l]Value is for dry (<0.3% moisture) specimens.
[m]General Electric's Lexan; Mobay Products Co.'s Merlon.
[n]At 158 F.
[o]At introductory price of $2.50, volumetric cost would be 11¢ per cu in.

Naugatuck Chemical

***ABS and nylon** are combined in this Lambert Lawnsweeper to provide a durable drive mechanism. Wheel and integral gear are injection molded of ABS in one piece; smaller drive gear is nylon.*

than any ABS grade, though low temperature impact grades of ABS have superior impact strengths at –40 F. Polycarbonates have higher strengths and substantially higher heat resistance. Modulus of medium impact ABS is higher than that of polycarbonate; 1000-hr creep data also indicate slightly better creep resistance at room temperature in the medium impact ABS, but inferior high temperature creep resistance. Extrapolations beyond 1000-hr life are not available for polycarbonates.

Like nylon, polycarbonates are self-extinguishing, permitting wider use of their somewhat superior electrical insulating properties.

Cost comparison

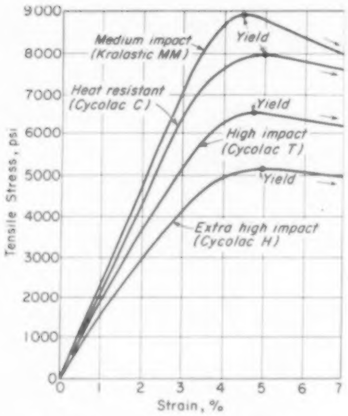
The materials most commonly compared with ABS on a cost basis are probably the modified high impact polystyrenes (1-1.5¢ per cu in.). Impact strength of modified polystyrenes can be as high as that of ABS. However, when impact strength is increased, rigidity, tensile strength and hardness decrease to a much greater degree than with ABS. Also, resistance to heat, weather, chemicals and staining of modified polystyrenes is substantially lower than that available in ABS materials.

Other materials that might be considered comparable on a cost basis are certain grades of cellulose acetate butyrate and propionate, and modified (high impact) acrylic.

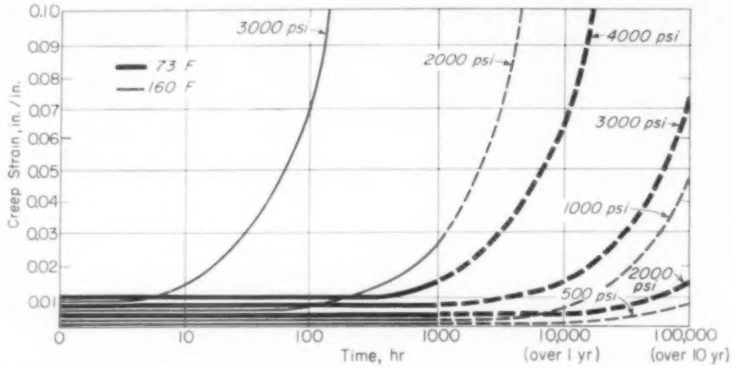
Competitive grades of butyrate and propionate cost slightly more than ABS materials (2.6-3¢ per cu in.). Although grades of butyrate and propionate are available with as good or better impact strength than some grades of ABS, these grades are less rigid, have lower heat resistance, and are not as hard.

The major advantage of butyrate and propionate in comparison with ABS materials is the depth and richness of colors obtainable.

The modified acrylic (Implex, costing about 2.5¢ per cu in.) is somewhat competitive with ABS for certain applications, such as women's shoe heels. The material has an impact strength of about 2 ft-lb per in. notch, has a rela-



1—*Initial portions of stress-strain curves for four types of ABS materials. Yield stress is always higher than rupture stress. Note similarity of strain at different yield stresses.* (Adapted from data from Marbon Chemical and Naugatuck Chemical.)



2—*Tensile creep of a medium impact grade of ABS (Kralastic MM) at various stresses, and at both room temperature (heavier curves) and 160 F. Dotted portions of curves indicate extrapolated data.*

tively good flexural modulus of just under 300,000 psi, and a relatively good tensile strength of about 5500 psi. Heat resistance is somewhat lower than that of most ABS grades and substantially lower than that of heat resistant ABS.

Properties of ABS in more detail

Fig 1 shows initial portions of typical stress-strain curves for ABS materials. Yield strength of ABS is always higher than rupture strength; consequently "tensile strength" values given in the table actually indicate stress at yield. Note that although yield strength varies considerably, strain at yield remains relatively consistent at about 4.5-5%.

As can be seen, there seems to be a proportional limit at about 3.5% strain. Between 3.5% and strain at yield, deformation appears to be both plastic and elastic, though predominantly elastic. With ABS materials, as with most other thermoplastics, data on effects of time and environments are not complete enough to warrant use of a specific proportional limit in design.

Time-dependent properties

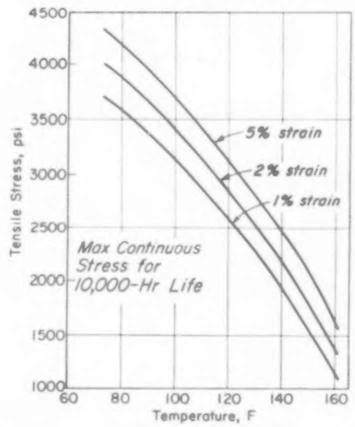
Data showing effects of long-term loading on ABS materials are relatively sparse. Fatigue data are noticeably lacking. Most creep data have been generated on ABS pipe, one of the important volume applications for these materials. But direct conversion of such data to apply to creep under other forms of loading is dangerous and can be misleading.

The creep data shown in Fig 2 apply to only one specific grade of medium impact ABS. Curves show tensile creep of a medium impact grade of ABS under various loads at both room temperature and 160 F. Data are extrapolated beyond the 1000-hr point. Fig 3 shows maximum continuous stress and corresponding strain for 10,000-hr life as a function of temperature.

Fig 4 shows apparent modulus of medium impact ABS compared with that of several other materials. (Apparent modulus is the ratio of stress to deformation at a given time, thus taking into consideration creep deformation under long-term loading).

Heat resistance

Compared with other thermoplastics, ABS materials have good heat resistance; grades are available for continuous use at temperatures of 185 to 230 F. As is the case with all plastic materials, specific maximum temperatures to

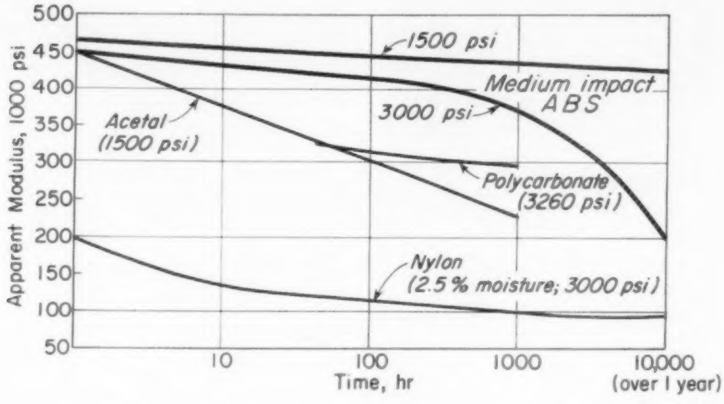


3—*Effect of temperature on maximum continuous stress at three strain levels for 10,000-hr life. Material is a medium impact ABS (Kralastic MM).* (Naugatuck Chemical)

which a material can be exposed depend on the stresses imposed on the part (both external and molded-in), the length of service, the type of exposure, and the degree of distortion or degradation that can be tolerated.

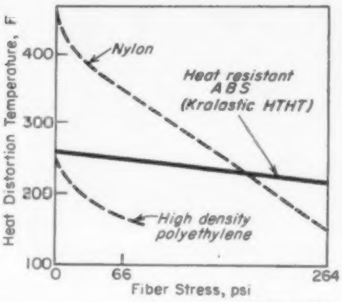
ABS and other amorphous polymers have a relatively flat temperature-stress curve, heat resistance being less stress-dependent than in the crystalline materials such as nylon, acetal, polyethylene and polypropylene. This difference is shown graphically in Fig 5 which compares load vs temperature for an ABS resin, with nylon and polyethylene.

Fig 6 compares effect of tem-



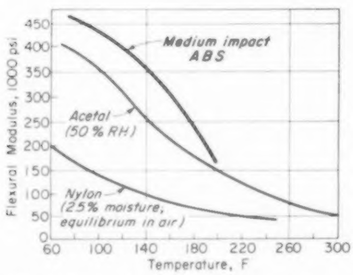
(Naugatuck Chemical)

4—*Apparent modulus of a medium impact ABS (Kralastic MM) at two different stress levels, compared with apparent moduli of polycarbonate (at 3260 psi stress), acetal (at 1500 psi stress), and nylon (at 3000 psi stress).*

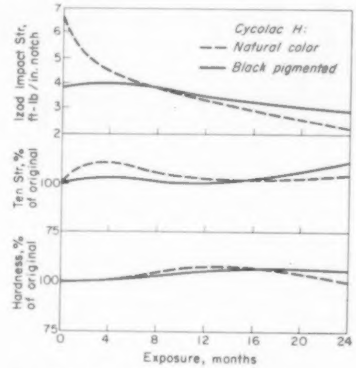


(Thompson)

5—*How temperature affects resistance to deformation of a heat resistant ABS, compared with nylon and polyethylene. Note the relatively flat curve, typical of amorphous thermoplastics.*



6—*Effect of temperature on flexural modulus of a medium impact ABS (Kralastic MM), compared with acetal and nylon.*



7—*Effects of two-year Florida exposure on impact strength, tensile strength and hardness of an extra-high-impact grade of ABS. Solid curves show protective effect of black pigmentation. (Marbon Chemical)*

perature on flexural modulus of a medium impact ABS, nylon, and acetal. The ABS material has a modulus of about 200,000 psi at the 185 F maximum recommended service temperature for this grade.

Electrical properties

The table shows the relatively good electrical insulating properties of ABS materials, which make them suitable for secondary insulating applications such as conduits and low voltage circuit bases. Flammability, however, which is similar to that of polystyrene, precludes the material from use as primary insulation.

Effects of chemicals and weather

In general ABS materials have excellent resistance to a wide range of chemicals, and, compared with other thermoplastics, good resistance to weathering.

Chemicals—If a part is to be used in a chemical environment, simulated service testing is always recommended. Since ABS materials supplied by different producers differ somewhat in chemical resistance, the materials suppliers should be consulted prior to service testing.

In general, ABS materials have excellent resistance to aqueous acids and alkalis. Concentrated sulfuric and nitric acids cause disintegration; concentrated phosphoric and hydrochloric acids have little effect. Immersion in alcohols, and animal, vegetable and mineral oils produces insignificant changes.

Glacial acetic acid, carbon tetrachloride, and aromatic hydrocarbons cause swelling and softening; esters, ketones, and ethylene dichloride are solvents for the resins.

Resistance of ABS to environmental stress cracking is generally good, but again differs with materials from the different suppliers.

Weathering—For the most part, weathering causes surface effects such as discoloration and loss of gloss. Its effect on mechanical properties is essentially a notching effect on the exposed portion of the part.

Prolonged outdoor exposure of ABS materials causes some changes in physical properties caused by this notching effect. Ultraviolet radiation causes a gradual formation of a very thin, hard, somewhat brittle veneer. When the veneer cracks, resistance to impact is lowered. However, the veneer as it is formed also apparently provides a degree of ultraviolet screening action, resulting in a leveling off of degradation. Fig 7 shows effects of two-year Florida exposure on impact strength, tensile strength and hardness of typical ABS specimens, both natural and pigmented. Pigmentation provides some protection from ultraviolet degradation.

Acknowledgments

Particular thanks are due C. R. Holt, Marbon Chemical, Div. of Borg-Warner Corp., and M. S. Thompson, Naugatuck Chemical, Div. of U. S. Rubber Co. for assistance in preparing and reviewing the manuscript.

Reference

Thompson, M. S., *Gum Plastics*, Reinhold Publishing Corp., 1958.

Motor slot and coil insulation—*Semiflexible plate has good springback, permitting fast assembly of motor slot insulation. Such plate is usually faced on one or both sides with glass cloth for resistance to tear and ease of insertion.*

Torroidal cores—*Conformability of impregnated paper (here in the form of tape) permits tight wrapping of cores.*

Transformer core tube and layer insulation—*Tape provides consistent dielectrics, uniformity of thicknesses, and good conformability for such appliances.*

These applications show that . . .

Impregnated Mica Paper Is Excellent Insulator

by F. Schwartz, *Mica Insulator, Div. of Minnesota Mining & Mfg. Co.*

■ Take fine mica splittings and produce a paper, and you have an excellent electrical insulator, but a low strength material. Using this mica paper as a base, add to it various types of synthetic resin impregnants, combine it with various types of reinforcing materials, and you obtain a large family of excellent insulating materials with a variety of mechanical, thermal and physical characteristics.

One of the most common forms in which such materials are used is so-called "plate." Plate consists of laminations of resin-impregnated papers, built up to a desired thickness. Nominal thickness typically ranges from 0.01-0.06 in. Resin content ranges from a low of 5% to as high as 35% depending on properties desired. Since the paper itself is consistent in quality and uniform in thickness, the impregnated product has reproducible and highly consistent quality.

Cost of mica paper products, of course, depends on such variables as type and quantity of resin, thickness, etc. In general, however, the materials are at least competitive in cost with resin-bonded mica splittings.

Two large classes of these materials are available: 1) resin-impregnated plate, and 2) combination materials. Nominal thicknesses, variations, and average dielectric strengths are specified in NEMA Standard No. ME 1-1956, "Manufactured Electrical Mica."

Resin-impregnated plate

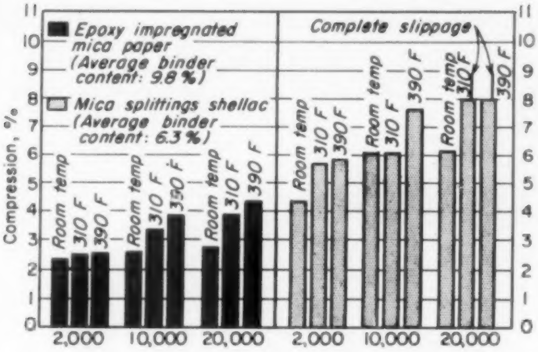
Epoxy and silicone resins are the most widely used resins in both rigid (molding or segment) and flexible plate. *Molding plate* is supplied as a prepreg material with a B-staged or partially cured resin. It can be molded to relatively complex contours (e.g., 90 deg bends can be molded without splitting or flaking), and cured to form a rigid insulating material.

Segment plate is supplied fully cured and can be punched, machined or sawed without splitting or flaking. In both the molding and cured plate materials, epoxy resins are used for optimum strength characteristics at both Class B (266 F) and Class F (311 F) temperatures. Although silicone impregnants provide somewhat lower strengths, they provide higher temperature resistance and are designed for Class H (356 F) service.

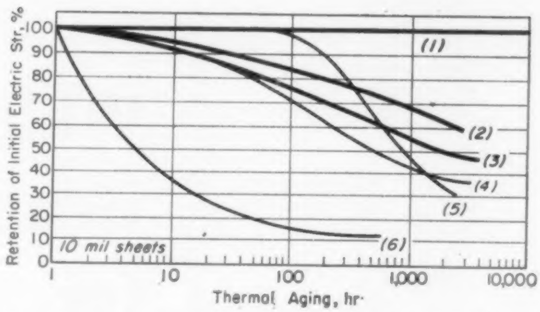
Combination materials

Where maximum strength is required, resin-impregnated mica paper can be combined with reinforcing materials, such as Mylar polyester film, glass cloth, or both. The reinforcing material can be provided in varying thicknesses, and on one or both sides. Combination materials are available either semi-cured or fully cured, and in either flexible or semi-flexible form.

Specialty grades include: 1) Transformer sheet consisting of thin (0.0009-0.002 in.), flexible silicone-impregnated mica paper designed for Class H layer insulation on small transformers. 2) Heater plate, consisting of an inorganic impregnant designed for maximum temperatures of 1000-1500 F; plate can be punched or sawed, and is generally available in thickness ranging from 0.010-



1—*Compression of epoxy-mica paper vs shellac-bonded mica splittings at various temperatures (ASTM D352).*



2—*Effect of thermal aging on electric strength 1) silicone-impregnated mica paper at 575 F; 2) epoxy-impregnated mica paper at 500 F; 3) epoxy-impregnated mica paper at 575 F; 4) silicone rubber-coated glass cloth at 500 F; 6) silicone-varnished glass cloth at 500 F.*

0.125 in. 3) Tapes, consisting of epoxy or silicone impregnated mica paper and a carrier, such as glass cloth or Mylar polyester film, or both. 4) Standard tubes in varying sizes made from mica paper with an epoxy, silicone or inorganic impregnant. 5) Capacitor grade mica paper, either supplied with no impregnant, or with a silicone resin impregnant.

Properties obtainable

The accompanying table lists properties of representative mica paper materials. Mica paper itself has a dielectric strength of 1000-1500 v per mil, and a power factor of 0.0006 at 86 F, and 0.0015 at 212 F. But its tensile strength is only 3.5-6 lb per in. width. As shown in the table, the resin impregnants and the reinforcing materials essentially provide additional strength at a minimum sacrifice in electricals.

The excellent dimensional stability of resin-impregnated paper under compression is shown in Fig 1 which compares compression (ASTM D352) of 0.020 in. thick epoxy bonded segment plate with that of shellac-bonded mica splittings.

Retention of dielectric characteristics on exposure to heat depends on the type and quantity of resin binder. The curves in Fig 2 show percent retention of electric strength versus thermal aging for impregnated mica paper vs several silicone-glass materials at different temperatures.

PROPERTIES OF SOME TYPICAL MICA PAPER PRODUCTS
(Based on specific grades of Isomica)

	Plate				Combination Plates and Tapes				Sheet Capacitor Insulation
	Molding	Segment		Flexible	Glass-Mylar[e]	Varnished Glass[f]	Glass-Mylar[g]	Varnished Glass[h]	
Resin Binder	Epoxy	Epoxy	Shellac	Epoxy	Epoxy	Epoxy	Epoxy	Silicone	Silicone
Composition, %									
Paper	75	90	90	65	45	55	45	25	73-76
Resin (max)	25	10	10	35	35	20	17	30	27-24
Glass Cloth	—	—	—	—	15	25	30	45	—
Polyester Film (Mylar)	—	—	—	—	5	—	8	—	—
Temperature Class[a]	B	B	B	F	F	F	F	H	H
Dielectric Str (min avg), v/mil[b]									
Short Time	1300	1300	750	1000	1100[c]	1150	1150	700[c]	3000 avg[c]
Step by Step	1100	1100	600	800	880[c]	920	920	—	—
Power Factor (60 cps, C-72/50/23)	0.008	0.012	0.015	0.05	0.04	0.05	0.06	0.02	0.0015 avg[c]
Specific Gravity	2.10	2.20	2.27	1.59	1.47	1.60	1.58	1.48	2.11
Thickness (avg), in.	0.010	0.030	0.030	0.010	0.006	0.012	0.012	0.015	0.0011
Ten Str (min avg), lb/in.	(30,000)[d]	(40,000)[d]	(30,000)[d]	50	90	150	90	150	—

[a]Operating temperatures: B: 266; F: 311; H: 356.
[b]2-in. electrodes except where noted.
[c]¼-in. electrodes
[d]Flexural strength, psi.
[e]0.0017 in. glass cloth one side; 0.00025 in. Mylar on other.
[f]0.003 in. varnished glass, both sides.
[g]Semi-flexible; 0.002 glass cloth one side; 0.001 in. Mylar on other.
[h]5 mil varnished glass cloth both sides.

Large Klystron vacuum tube *requires 16 metal-to-ceramic brazed joints, as well as many metal-to-metal joints.*

Which Brazing Alloys for Vacuum Systems?

Composition limitations and absence of flux make proper alloy selection especially vital.

by Walter Hack, *Western Gold and Platinum Works*

■ The necessity of producing completely vacuum-tight joints by brazing involves consideration of factors which would be of less, or no, importance if the joint were merely required to be mechanically strong and reasonably air-tight. Such factors will affect the selection of brazing alloys and will alter brazing procedures.

Brazing alloys must have these three characteristics:

1. *Constituents of low vapor pressure.* High vacuum service means that only low vapor pressure elements may be present in the brazing alloys. Some such elements have melting points too high to be practicable. Thus, the list of suitable elements reduces to copper, silver, gold, nickel, indium and tin. It is essential, too, that small traces of zinc and cadmium, elements widely used in conventional brazing alloys, not be present as impurities.

2. *Ability to wet and flow.* These qualities, desirable in all brazing alloys, are of greater importance than normal when brazing for vacuum systems. The reason is that fluxes, which are a great aid to wetting and flowing, cannot generally be used. Their subsequent complete removal is questionable, and any flux trapped in the final joint may form voids detrimental from both strength and leakage standpoints.

Wetting is the ability of the molten brazing alloy to adhere to the surface of a metal in the solid state and, when cooled below its solidus temperature (see box on next page), to make a strong bond to that metal. Wetting is a function not only of the brazing alloy, but of the nature of the metal or metals to be joined. There is considerable evidence that, in order to wet well, a molten metal must be capable of dissolving, or alloying with, some of the metal on which it flows.

Flow is the property of a brazing alloy that determines the distance it will travel away from its original position due to the action of capillary forces. To flow well, an alloy must not suffer an appreciable increase in its liquidus temperature even though its composition is altered by the addition of the metal it has dissolved. This is important because the brazing operation is carried out at tem-

peratures just above the liquidus.

3. *Freedom from traces and impurities.* Alloys must have been produced with more care than usual, not only to prevent inclusion of high-vapor-pressure elements but also to exclude such common impurities as dirt and carbon which are often picked up during the casting of the original ingot and subsequent wire drawing or sheet rolling.

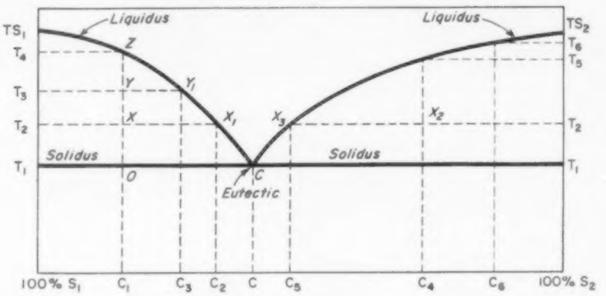
Although such impurities generally rise to the surface of molten metals—where they are not too objectionable—there is always the danger of gassing or voids. Therefore the highest quality brazing alloys obtainable should be used.

Purity is also important from the standpoint of oxides which may be present, or may form, during brazing. Because fluxes cannot be used, a hydrogen atmosphere is generally required during brazing to prevent oxidation and reduce minor amounts of oxides present in metallic form. The major alternative to hydrogen is a vacuum atmosphere. In some cases argon or helium is used.

Base metals used may affect these characteristics

Factors that determine the selection of a brazing alloy, for any application, include the expected maximum operating temperature of the part (which will not be discussed in this article), the number of successive brazes required to produce the part, and the nature of the materials to be joined. This third factor—the nature of the base metals—is particularly important when brazing for vacuum service because it affects the wetting and flowing of the brazing alloy. A study of equilibrium diagram theory (see box) will make the following discussions clearer.

Steel to steel. Copper brazing alloys are highly satisfactory from the standpoint of both wetting and flowing on steel. The excellent flow characteristics are due to the fact that as the copper melts it takes into solution a small amount of iron. The surface layer of the steel is saturated with



Equilibrium Diagram Explains Brazing Problems

Analyzing the diagram

This hypothetical diagram is a plot of the liquid and solid states of all possible compositions consisting of metals S_1 and S_2.

Liquidus — The two heavy curves, TS_1-C-TS_2, represent the liquidus; above this temperature any composition is liquid. (The liquidus temperature of composition C_1 is T_4, as indicated by point Z.)

Solidus—The heavy horizontal line T_1-C-T_1 is the solidus; below this line all compositions are entirely solid. T_1 is the solidus temperature for all compositions (e.g., points C and O).

Eutectic — Composition C is the eutectic. When an alloy of this composition is heated it remains entirely in the solid state until temperature T_1 is reached at which point it becomes entirely liquid. T_1 is both the solidus and liquidus temperature of composition C. The eutectic is entirely liquid at a lower temperature than any other composition in the diagram.

Liquid-solid state — Unlike composition C, any other composition will not convert directly from solid to liquid at one temperature, although all compositions begin this conversion at T_1. Composition C_1, for example, will be partly solid and partly liquid at any temperature between T_1 and T_4 (such as T_2 or T_3, indicated by points X and Y).

Composition of each state—At temperature T_2 (point X), composition C_1 is separated into a solid of composition S_1 (the pure metal) and a liquid of composition C_2 (point X_1). The liquid must be of composition C_2 because this is the only composition that can be liquid at temperature T_2. (It cannot be C_5 because the original composition contained more S_1 than S_2.)

Defining the problems

Brazing alloys that are not eutectic compositions present a danger if parts being brazed are disturbed during the time the alloy passes through the part solid-part liquid condition. Any movement during this period may produce cracks in the braze metal.

A second type of difficulty can be illustrated by assuming that S_1 is silver, S_2 is copper, and the parts to be brazed are copper. If the brazing alloy has composition C_4 at T_1, then at T_2 the liquid portion changes to composition C_5 having a higher copper content. But the copper in the base metal is also soluble in this liquid phase. If the rise in temperature is not rapid enough between T_1 and T_5 (the liquidus temperature of C_4) the alloy may dissolve enough copper to change its composition to C_6 with a resultant higher liquidus T_6. If the furnace temperature has been set for T_5, the braze metal will never become completely liquid and will not flow adequately.

Another aspect of the same phenomenon occurs if the brazing alloy is allowed to remain at a temperature above the liquidus for so long a time that enough copper is dissolved to alter the composition to one with a higher liquidus. In this case a solid phase will slowly crystallize from the melt and weaken the brazed joint.

iron which is still in the molten state. The bulk of the molten copper will flow away because of capillary forces, and the process will be repeated until the supply of copper is exhausted. An actual equilibrium diagram plot for the copper-iron system would show that molten copper can dissolve up to 2.8% iron without raising the liquidus temperature of the resultant alloy more than 52 °F.

Nickel to nickel. The commonly used eutectic brazing composition of 72 silver-28 copper will wet and flow readily on nickel. This is because nickel is highly soluble in copper. Gold-copper and gold-copper-nickel alloys can also be used successfully.

Pure molten silver will wet nickel well but flows poorly unless the silver is alloyed with copper. The reason is that silver dissolves extremely little nickel; when a slight amount is brought into solution the liquidus of the resultant alloy rises very rapidly and the newly formed alloy freezes.

Copper to copper. The best alloys are the silver-copper eutectic, the gold-copper alloys and the gold-copper-nickel alloys.

Again, pure silver is unsatisfactory. The copper-base metal is highly soluble in silver. The melting point of the alloy of silver and copper is lower than the melting point of pure silver, and the silver will penetrate into the copper rather than flow out on the surface. The same effect would occur if pure gold were used.

Copper to nickel. As with copper to copper, or nickel to nickel, the best alloys prove to be the silver-copper eutectic, the gold-copper alloys and the gold-copper-nickel alloys.

Glass-sealing alloys (e.g., Rodar, Kovar and Fernico). These alloys, consisting of iron, cobalt and nickel, are best wet by copper, gold-copper, gold-nickel and gold-copper-nickel brazing alloys. It is true that the silver-copper eutectic would wet the glass-sealing alloys well, but it is not usually acceptable because of the tendency of silver to penetrate the grain boundaries of the base alloys and cause embrittlement.

Among the acceptable alloys, it has been found that gold-copper-nickel and gold-nickel alloys flow better than pure copper and gold-copper alloys. The better flow of the nickel-containing alloys is probably due to the solubility of oxygen and nickel oxide in molten nickel. That is, the nickel may actually dissolve minor amounts of oxides off the surface of the metals. Wetting and flow may also be enhanced by the removal of surface carbon; carbon will form a solid solution with nickel at brazing temperatures.

Stainless steel. Excellent wetting and flowing is obtained with an 82 gold-18 nickel alloy. This fact, too, gives credibility to the supposition that the good wetting and flowing characteristics of the nickel-bearing gold alloys are due to the solubility of carbon and oxygen in nickel.

Molybdenum or tungsten. Brazing alloys that flow well are gold-nickel or gold-copper-nickel alloys with high nickel content. Molybdenum and tungsten are not wet by the silver-copper alloys and poorly wet by the gold-copper alloys.

Economy and design factors may dictate final selection

If, as seen above, there is often a choice between such brazing alloys as the silver-copper eutectic, the gold-copper alloys and the gold-copper-nickel alloys, what additional factors might narrow the selection?

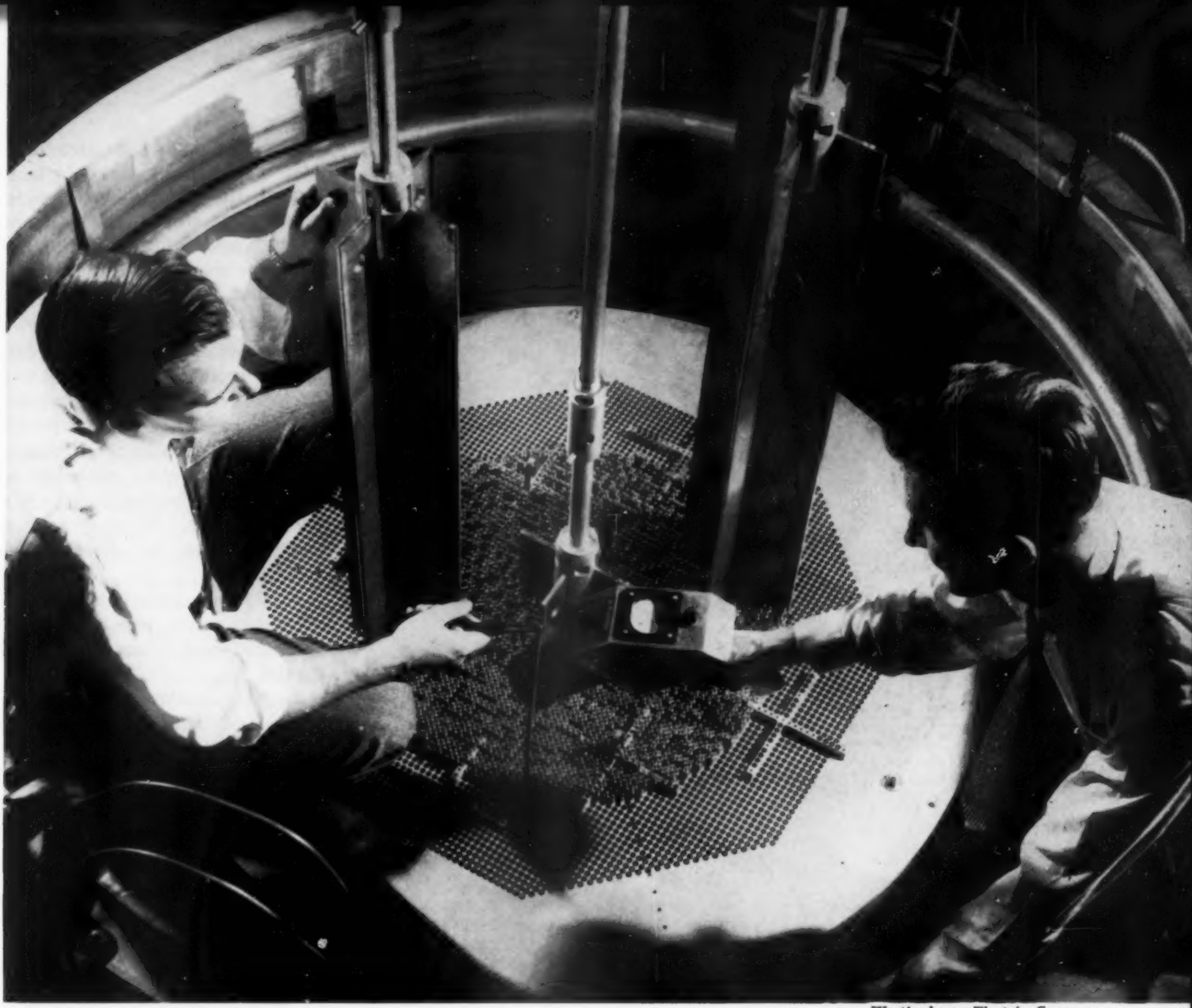
1. Economic considerations would dictate the use of the silver-copper eutectic. However, the other two brazing alloys have considerably lower vapor pressures, and vacuum service conditions may dictate the use of these alloys although they cost ten times as much as the eutectic alloy.

2. Successive brazing requirements may also require the gold brazing alloys; they have a higher liquidus and solidus than the eutectic. In successive brazing, the solidus of the first brazing alloy used must be higher than the liquidus of the next brazing alloy. Thus, the first joint will not soften and deform during the second brazing operation.

3. Long tight seams, or other special requirements, may dictate the choice between gold-copper alloys which do or do not contain nickel. In such cases the nickel-bearing alloy is usually superior because of its excellent flow characteristics.

4. Different coefficients of expansion between base metals—such as copper and molybdenum—present difficult brazing problems. The solution is the use of a brazing alloy with little or no temperature differential between liquid and solid states, i.e., an alloy that is close to the eutectic composition. This is because any differential movement between parts during the time when the brazing alloy in the weak liquid-solid state will open up cracks in the body of the brazing alloy. The best alloy is the low melting eutectic alloy of the gold-nickel system. It has excellent wetting characteristics and high tensile strength. An alternative, dictated by its lower melting point, may be an 81% gold-copper-nickel alloy. It has a solidus of 1620 F and a liquidus of 1638 F.

MORE ENGINEERING & DESIGN



Westinghouse Electric Corp.

Radioactivity measurements *on fuel rods of this experimental reactor will further design of new 134,000-kw nuclear power plant now under construction for Yankee Atomic Electric Co. in New England.*

How Radiation Affects Engineering Materials

by Richard E. Bowman, *Radiation Effects Information Center, Battelle Memorial Institute*

M/DE Manual No. 173
July, 1960

Radiation has been added to the growing list of combined environments that the engineer must now consider. Here is an up-to-date summary of how it affects commonly used materials such as:

- *Structural metals*
- *Inorganic nonmetallics*
- *Elastomers*
- *Plastics*
- *Organic fluids*

Irradiated semiconductor *specimens being removed from a six-inch beam tube of the Battelle Research Reactor.*

The radiation environment

Gamma rays and neutrons cause property changes

All materials are affected to some extent by radiation, although small doses do not usually cause appreciable effects. In general, the organic and semiconductor materials are severely affected by radiation, whereas metals and ceramics are more resistant. Organic materials are particularly susceptible to damage or change in properties by irradiation (both gamma and neutron) because of their covalent chemical bonds. Furthermore, they are adversely affected by environments such as extreme temperatures, oxidizing atmospheres and mechanical degradation. Thus, the designer has to understand the combined effect of superimposing these environments on the radiation environment.

Radiation effects can be classified into two types: transient and permanent. Transient effects are property changes that occur during an irradiation, but which disappear when the radiation field is removed. These effects will not concern us here. Our primary concern is the permanent effects that begin during an irradiation and remain after the field is removed. In order to better understand these effects it is necessary to learn something about the basic damage mechanisms caused by radiation.

What causes damage?

In general, little radiation damage is caused by alpha and beta particles released during nuclear fission since they can be readily removed by shielding. Of primary concern in selecting materials are the more penetrating gamma rays and neutrons. These forms of radiation can be described as follows:

1. Gamma radiation: Electromagnetic waves which are more energetic and penetrating than x-rays.

2. Fast neutrons: Uncharged nuclear particles moving at very high velocities and having appreciable kinetic energy.

3. Thermal neutrons: Neutrons moving at velocities equal to the kinetic motion of molecules.

Gamma radiation effects result from the interaction of gamma rays with electrons of the materials being irradiated. Basically, this interaction is an ionization process. Thus, gamma radiation is principally responsible for the permanent damage to organic compounds. Teflon, for example, softens and crumbles, and certain hydrocarbon fluids undergo gassing and decomposition. It has little effect on inorganic or crystalline materials, including metals, other than to cause heating. However, it can cause transient changes in the electrical characteristics of semiconductor devices, gas-filled electron tubes, and various insulating materials.

Fast neutrons, being uncharged particles, can lose energy only by direct collision with atoms. Moreover, once a collision occurs, the atoms, in turn, rapidly strike and displace other atoms. These collisions produce vacancies, interstitials, thermal spikes, impurity atoms and ionization effects. Although not completely understood, these effects cause property changes. For example, fast neu-

trons increase the yield strength and decrease the ductility of certain metals, and cause permanent changes in the electrical properties of semiconductor materials.

Thermal neutrons have little direct effect on materials aside from inducing radioactivity. One exception is the cracking of glass vacuum tube envelopes caused by the absorption of thermal neutrons by the boron in the glass.

How damage is measured

Although it is relatively easy to describe radiation effects it is quite difficult to measure these effects quantitatively. The entire field of radiation dosimetry has grown out of efforts to measure and interpret radiation dose. Following are four units of measurement that we will use in discussing gamma and neutron irradiation.

1. Ergs per gm (C): ergs per gram referred to carbon is equivalent to the energy absorbed from a gamma field per unit mass of carbon (as a reference material). In the case of organic materials it is approximately equal to the energy absorbed per gram of sample.

2. Ergs per gm: energy absorbed per gram of sample.

3. n per sq cm: unit of integrated flux consisting of the neutron density, n, multiplied by the neutron velocity in cm per sec, and by the exposure time in sec. Fast neutrons are defined as those having energies greater than about 0.5 mev (million electron volts).

4. $(nv_o)t$: unit of integrated thermal neutron flux where (nv_o) is the neutron density normalized to the velocity of 2200 meters per sec.

In addition, the terms "damage threshold" and "25% damage" are frequently used to describe radiation damage in materials, particularly organic materials. "Damage threshold" refers to the radiation exposure required to change at least one physical property of the material. When one property is changed by 25%, the material is said to have reached "25% damage."

Structural metals

generally have best radiation resistance

Structural metals are not as susceptible to radiation damage as nonmetallic materials such as polymers, organic fluids and semiconductor materials. Detectable changes in the mechanical properties of metals do not appear until the integrated fast neutron flux reaches a level of about 10^{19} n per sq cm. However, physical properties can be affected at lower levels. For example, the magnetic properties of some ferrous alloys deteriorate appreciably at integrated fast flux levels of 10^{17} n per sq cm.

A general summary of the effect radiation has on metals is given in Table 1. (See also, "Radiation Damage In Metals," M/DE, Jan '60, p 89.) In general, the effects of radiation in metals are analogous to that of cold work, although the overall effects are less severe. Such effects are not usually desirable and can be minimized by decreasing radiation dose, and/or increasing temperatures during irradiation. Like cold working, radiation damage can be repaired or removed by annealing.

Investigations of the effects of neutrons on metals have been made at integrated fast fluxes up to 10^{22} n per sq cm and at temperatures up to 750 F. However, most data have been obtained at or near room temperature and the studies made at very high and very low temperatures have been of a basic scientific nature and have not provided materials engineering data.

Aside from neutron effects, two important secondary effects that should be considered are induced radioactivity and gamma heating. Cobalt-bearing alloys (even those containing cobalt only as an impurity) become sources of gamma radiation which may make them unsuitable for some applications

TABLE 1—GENERAL SUMMARY OF HOW IRRADIATION AFFECTS METALS

Property	Effect
Tensile Yield Strength	Increases as much as several hundred percent in annealed materials, smaller increases in metals previously strengthened by cold working or heat treatment
Ultimate Tensile Strength	Increases up to 75% in annealed and to lesser extent in strengthened metals
Ductility	Decreases by as much as one-third in annealed metals and somewhat less in strengthened condition
Elastic Constant	Limited data indicate little or no change
Work Hardenability	Decreases
Impact Strength	Decreases—ductile to brittle transition temperature elevated by as much as 180 F
Creep	Little or no effect
Fatigue Strength	Limited data show no effect
Hardness	Increases moderately
Damping Capacity	Unaffected
Density	Decreases by as much as 0.2%
Diffusion Coefficient	Limited data show slight increase
Electrical Resistivity	Increases by as much as 10%
Phase Transformation	Possible in certain systems
Microstructure	Changes observed in certain systems under selected conditions
Thermoelectric emf	Slight change possible
Thermal Conductivity	Limited data show moderate decrease
Corrosion Resistance	Little or no change
Induced Radiation	Depends on concentration and cross section of components
Dimensional Stability	Moderately affected
Internal Friction	Limited data show little or no effect

TABLE 2—EFFECT OF NEUTRON IRRADIATION ON THE TENSILE PROPERTIES OF METALS

Metal ↓	Condition	Irradiation		Yield Strength		Tensile Strength		Elongation	
		Temp, F	Integrated Fast Neutron Flux, n/sq cm	Unirrad, 1000 psi	Change After Irrad, 1000 psi	Unirrad, 1000 psi	Change After Irrad, 1000 psi	Unirrad, %	Change After Irrad, %
CARBON STEELS									
ASTM A212B	Normalized at 1904 F. ASTM 5 grain size	176	10^{19}	51	14.4	75	6.8	23	−5
ASTM A212B	Same as above	176	10^{20}	51	42	75	25	23	−18
ASTM A302B	—	500	3.7×10^{18}	65	7.1	91.5	3.8	26	−2
ASTM A302B	—	698	3.7×10^{18}	64.2	3.3	89.8	2.8	27	−1
STAINLESS STEELS									
347	—	—	2.6×10^{22}	61.6	39.2	95.8	11.4	63.2	19.2
316	Annealed	104	5×10^{20}	—	—	79	71	—	—
440 C	Hardened	—	5×10^{19}	185	18	205	35	—	—
301	—	176	4×10^{19}	38.4	48.6	98.7	14.5	56	−8
304 ELC	—	176	8×10^{19}	24.4	51.1	86.3	17.5	63	−5
302	—	176	4×10^{19}	33.9	50.1	95.5	15.8	—	—
302 B	—	176	4×10^{19}	33.5	48	107.8	17.2	—	—
305	—	176	4×10^{19}	32.1	39.3	98	5.6	—	—
347	—	176	4×10^{19}	37	59.5	97.6	17.2	49	−24
321	—	176	8×10^{19}	31.2	59.4	84.8	21	—	—
410	Annealed	—	10^{20}	147.7	35.1	177	24	20	−5
ALUMINUM ALLOYS									
1100	—	—	2.6×10^{22}	18.4	8.1	20.3	10.1	22.3	0.7
356	—	—	2.6×10^{22}	24.1	11.9	32.4	12.6	2.7	−1.2
1100-0	—	149	10^{20}	6.8	10.3	13.6	12.4	38.2	−17
1100-H14	—	149	10^{20}	16.6	7.4	17.3	8.7	6	−0.5
6061-0	—	149	10^{20}	9.5	16.1	18.1	19.2	28.8	−6.4
6061-T6	—	149	10^{20}	38.5	5.9	45	5.6	17.5	−1.3
NICKEL ALLOYS									
Monel	As received	104	4×10^{19}	—	—	85	11	33	−23
K Monel[a]	As received	104	4×10^{19}	—	—	211	15	1	+1
K Monel	As received	104	4×10^{19}	—	—	123	11	11	−8
Inconel[a]	As received	104	4×10^{19}	—	—	151	21	2	—
Inconel	As received	104	4×10^{19}	—	—	106	10	31	−2
Inconel X[a]	As received	104	4×10^{19}	—	—	174	29	2	—
Inconel X	As received	104	4×10^{19}	—	—	126	7	37	−14
Hastelloy C	Cast	—	4×10^{19}	—	—	80	27	—	—
Hastelloy C	Wrought	104	4×10^{19}	—	—	138	4	20	−8
Hastelloy C[a]	Wrought	104	4×10^{19}	—	—	198	22	2	—
Hastelloy X	Annealed	—	5×10^{19}	49.4	50.8	112.5	16.8	52	−2
Inconel 702	Annealed	—	5×10^{19}	42.6	58.5	94.9	18.2	67	−17
Inconel X	Aged twice	—	2×10^{20}	103.[illegible]	55.4	170.1	−8.8	28	−14
Inconel X	Aged once	—	2×10^{20}	120.3	50.5	184.3	−10.3	23	−10
K Monel	Annealed	—	5×10^{19}	132.4	35.2	163.4	5.3	22	−10
OTHER METALS									
Copper	Annealed	212	5×10^{19}	8.4	21.9	27.1	7.2	42.2	−14.7
Nickel	Annealed	212	5×10^{19}	36.2	25.3	58.6	4.3	34.4	−11
Molybdenum	Stress relieved	212	5×10^{19}	93.7	5.7	99.8	4.5	23.6	−1.6
Tungsten	Fully recrystallized	212	5×10^{19}	—	—	137	15	0	0
Titanium	Annealed	212	5×10^{19}	79.8	8.9	83.4	8.8	10.4	−2.1
Zirconium	Heavily cold worked	212	5×10^{19}	107	−1	123.5	0.8	3.5	0.7
Tantalloy	As received	—	5×10^{19}	—	—	136	29	29	−15
Tungsten	As received	—	5×10^{19}	—	—	153	−36	0	0
Tantalum	As received	—	5×10^{19}	—	—	68	19	21	−4
Tantung G	As received	—	5×10^{19}	—	—	73	−4	5	−1
Stellite 3	As received	—	5×10^{19}	—	—	86	8	—	Low
Zircaloy 2	Annealed	122	10^{21}	44.1	25.9	68.4	11.6	23	−8
Zircaloy 2	50% cold worked	122	1×10^{21}	79.6	24.9	98.3	16.2	19.5	−10.3
QMV Beryllium	—	—	2×10^{21}	24.5	—	35.7	15.7	1.4	−1.2
QMV Beryllium	—	—	7×10^{21}	24.5	—	35.7	14.7	1.4	−1.2
Zirconium	Annealed	158	2×10^{20}	34.5	21.6	64.1	7.1	33	−11
Zirconium	20% cold worked	158	2×10^{20}	71.3	13.4	78	10.5	14	—
Zirconium	50% cold worked	158	2×10^{20}	83.7	10.8	86.7	9	11	−4

[a]Notched specimens.

even though their structural characteristics are not significantly affected. Although both neutrons and gamma rays transfer energy to metals and cause internal heating, the major heating effect is caused by the gammas. In fact, if sufficient cooling is not provided, high gamma fluxes can cause melting.

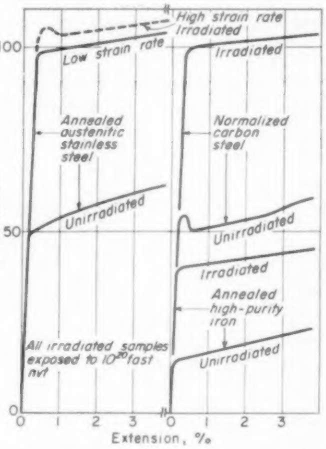
Tensile properties

A complete summary of the effects of radiation on metals is shown in Table 2. These data show that in most cases, fast neutron irradiation increases the yield strength of metals in a manner analogous to cold working. This effect tends to level out with increasing exposure (*Bruch, et al.*). The yield strength of annealed metals is approximately doubled after irradiation, and in some cases it can increase as much as 4.5 times.

Neutron irradiation also increases the tensile strength of metals, but to a lesser extent than it does yield strength. A decrease in tensile strength has been reported with some hardened or cold-worked metals and it is believed that this may be caused by radiation induced structural effects or gamma heating.

Because of the increase in yield and tensile strength by neutron bombardment, the ductility of a metal is generally lowered. Loss of ductility can range from one-fifth to one-third or more; however, it may be restored by annealing.

If the strain rate is sufficiently



1 Comparison *of stress-strain curves for unirradiated and irradiated metals.*

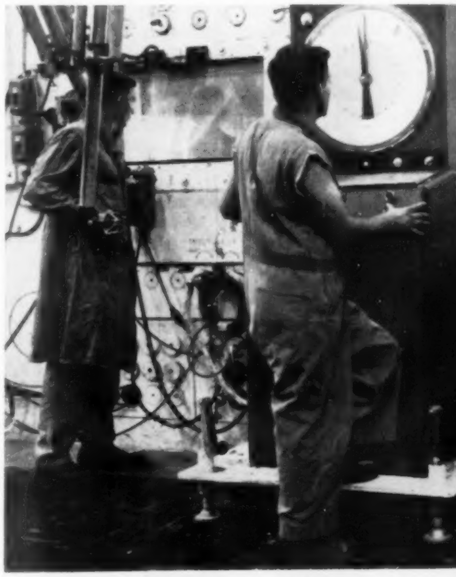
TABLE 3—EFFECT OF NEUTRON IRRADIATION ON THE IMPACT PROPERTIES OF METALS

Metal ↓	Type of Specimen	Irradiation		Change in Transition Temp, °F[a]
		Temp, F	Integrated Fast Neutron Flux, n/sq cm	
FERROUS METALS				
Iron	—	527	10^{20}	Increases
ASTM A302B Steel[b]...	Standard V-notch Charpy	500	4×10^{18}	11
Same as above	Same as above	698	4×10^{18}	11
ASTM A212B Steel[c]...	Subsize Izod	176	10^{19}	9
Same as above	Same as above	176	10^{20}	103
ASTM A212 Steel.....	Subsize notched cylinders	122	10^{20}	151
ASTM A212 Steel.....	Same as above	428	2×10^{18}	34
ASTM A212 Steel.....	Same as above	572	2×10^{18}	45
NONFERROUS METALS				
Tungsten............	Subsize tension test	212	5×10^{19}	14
Molybdenum.........	Subsize tension test	212	5×10^{19}	185
Zirconium	Subsize Izod	104	5×10^{19}	Small
Aluminum............	—	527	10^{20}	Decreases
Copper	—	527	10^{20}	Increases
Nickel	—	527	10^{20}	Increases

[a]See text. Numerical changes indicated are positive.
[b]Normalized at 1650 F. [c]Normalized at 1900 F.

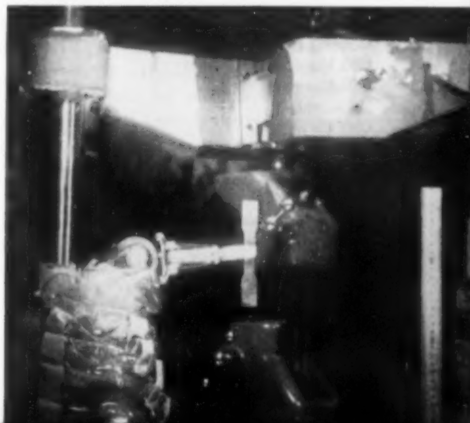
Overall view *of Battelle's hot cell facilities for studying radiation effects on materials that are radioactive.*

How radiation effects are studied



Remote tensile test *in operation. Operator at left is manipulating specimen. Operator at right is monitoring and recording data.*

Interior view *of remote testing chamber showing irradiated metal specimen being installed.*



high, neutron irradiation tends to produce a drop-in-load yield point, primarily in face-centered-cubic metals. And, as shown in Fig 1, irradiated carbon steels tend to lose their yield point.

Impact properties

Neutron irradiation affects the fracture behavior of structural metals and must be taken into account for design purposes. As shown in Table 3, irradiation tends to increase transition temperature. It is well-known that the fracture characteristics of body-centered-cubic metals such as iron, molybdenum and tungsten change sharply over a restricted range of temperature, called the ductile-brittle range. As the name implies, brittle fracture with little energy absorption occurs below this range, and ductile fracture with greater energy absorption occurs above the range. The transition temperature is a more or less arbitrary temperature within this range and is used for comparing fracture behavior on identical specimens tested under identical conditions.

Hardness

Since neutron bombardment causes atomic displacements and pinning of dislocations it increases the ability of a metal to resist indentation. The hardness of a metal can be increased as much as 100 Brinell by irradiation.

Hardness is a relatively easy property to measure out of pile, and for this reason considerable data (see Table 4) have been accumulated for a variety of metals. These data (see *Sutton* and *Leeser*) indicate that hardening:

1. Is greater for softer metals than for those already hardened.
2. Is not a direct function of carbon content of steels.
3. Is preserved at room temperature, but changes caused by irradiation are lessened at high temperature.
4. Proceeds at a decreasing rate during irradiation and probably approaches a saturation limit well below the fully embrittled condition.

Density and dimension

As shown in Table 5, structural metals do not exhibit large changes in density and dimension under neutron irradiation. In general, density decreases and falls within the ±0.05% limit of experimental accuracy. An exception to this trend is the cobalt alloys; they show a slight increase in density after irradiation.

Integrated fluxes above 10^{19} n per sq cm can be harmful where small tolerances are required. In general, metal-ceramic combina-

TABLE 4—EFFECT OF NEUTRON IRRADIATION ON THE HARDNESS OF METALS

Metal ↓	Condition	Irradiation		Brinell Hardness	
		Temp, F	Integrated Fast Flux, n/sq cm	Unirradiated	Change After Irradiation[c]
PLAIN CARBON STEELS					
1018	Annealed	104	10^{19}	138	23
1018	Hardened	104	10^{19}	237	6
1042	Annealed	104	10^{19}	225	−38
1042	Hardened	104	10^{19}	390	36
1045	Annealed	104	10^{20}	187	0
1095	Annealed	104	10^{19}	290	25
1095	Hardened	104	10^{19}	535	0
STAINLESS STEELS					
410	Annealed	—	3×10^{20}	318	10
16-1 Croloy	Annealed	—	8×10^{19}	159	57
347 C	Annealed	203	10^{20}	—	82
304	Surface nitrided	104	5×10^{20}	654	156
316	Annealed	104	5×10^{20}	154	74
410	Surface nitrided	104	5×10^{20}	656	84
440 C	Hardened	104	5×10^{20}	545	0
440 C	Hardened	—	4×10^{19}	461	73
USS "W"	Hardened	104	5×10^{20}	461	0
NICKEL ALLOYS					
Hastelloy C	Cast	—	5×10^{19}	228	132
Hastelloy C	Wrought	104	4×10^{19}	209	0
Monel	Annealed	104	4×10^{19}	150	59
K Monel	As received	104	4×10^{19}	260	25
Inconel	As received	104	4×10^{19}	175	65
Inconel X	Annealed	104	4×10^{19}	209	56
Hastelloy X	Annealed	—	5×10^{19}	172	44
Inconel 702	Annealed	—	5×10^{19}	156	60
Inconel X	Aged twice	—	10^{19}	265	21
Inconel X	Aged once	—	10^{19}	301	17
K Monel	Annealed	—	5×10^{19}	271	9
OTHER METALS					
Copper[a,b]	—	194	5×10^{20}	44	56
Nickel[a,b]	—	194	5×10^{20}	61	55
Titanium (75A)[b]	—	194	5×10^{20}	177	33
Zirconium[a,b]	—	194	5×10^{20}	69	21
Iron[a,b]	—	194	5×10^{20}	53	42
Molybdenum[b]	—	194	5×10^{20}	204	23
1100 Aluminum	—	—	2×10^{21}	38	34
1100 Aluminum	—	—	3×10^{22}	38	38
356 Aluminum	—	—	2×10^{21}	67	29
QMV Beryllium	—	—	2×10^{21}	127	52
Stellite 3	—	—	5×10^{19}	420	55
Tungsten	—	—	5×10^{19}	—	0
Tantung G	—	—	5×10^{19}	—	0
Tantalum	—	—	5×10^{19}	147	53

[a]High purity. [b]Annealed.
[c]All changes are positive except where noted.

tions (such as Kennametal 150A and Carboloy cermets) show a larger decrease in density and greater dimensional instability after irradiation than common metals such as steel.

Electrical resistivity

Since neutron irradiation causes lattice imperfections, it produces a noticeable increase in electrical resistivity, especially at lower temperatures where the effects are unable to anneal out. Below saturation it seems reasonable to assume that this increase is directly proportional to the integrated fast neutron flux in view of the almost linear relationship found for gold, silver and copper irradiated with 12-mev neutrons (*Cooper et al.*). Between 86 and 536 F, increases are limited to about 5%, except in high-melting metals such as tungsten and molybdenum, as indicated in Table 6.

For face-centered-cubic metals (copper, nickel and 347 stainless steel) the increase in electrical resistivity is inversely related to original resistivity. As indicated by *Bruch et al.*, the relationships of body-centered-cubic metals (iron and molybdenum) and close-packed-hexagonal metals (titanium and zirconium) are approximately parallel to and larger in magnitude than those of the face-centered-cubic metals.

TABLE 5—EFFECT OF NEUTRON IRRADIATION ON THE DENSITY OF METALS AND ALLOYS

Material ↓	Irradiation		Density	
	Temp, F	Integrated Fast Neutron Flux, n/sq cm	Unirrad, lb/cu in.	Change After Irrad, %
1100 Aluminum	—	240	0.0978	−0.004
356 Aluminum	—	240	0.0962	−0.02
QMV Beryllium	—	240	0.0665	0
347 Stainless Steel	—	240	0.285	−0.003
316 Stainless Steel	104	3.5	0.288	−0.06
347 Stainless Steel	104	3.5	0.286	−0.09
347 + Ta Stainless Steel	104	3.5	0.286	−0.04
410 Stainless Steel	104	3.5	0.277	−0.05
"A" Nickel	104	3.5	0.321	−0.07
Monel	104	3.5	0.319	−0.05
Stellite 3	104	3.5	0.309	0.06
Stellite 6	104	3.5	0.301	0.11
ASTM A212 Steel	104	3.5	0.283	0
Tantalum	—	5	—	−0.10
Tungsten	—	5	—	−0.15
Tantung G	—	5	—	−0.20 to −0.25
WC-Co, TAC-Co	—	8	—	−0.3 to −0.6
TiC-Ni	—	8	—	−0.3 to −0.6

TABLE 6—EFFECT OF NEUTRON IRRADIATION ON THE ELECTRICAL RESISTIVITY OF METALS

Metal ↓	Irradiation		Resistivity Change, %[b]
	Temp, F	Integrated Fast Neutron Flux, n/sq cm	
Copper	−238	10^{19}	20
Aluminum	−238	10^{19}	33
Stainless Steels (304, 309, 347)	536[a]	4×10^{19}	5
Tantalum	—	5×10^{19}	0
Tantung G	—	5×10^{19}	0
Tungsten	—	5×10^{19}	40

[a] Flowing water used.
[b] All changes are positive.

Inorganic materials

show many changes in physical and mechanical properties

Many other inorganic materials have been studied closely to find out how they perform in nuclear environments. The most important materials from a design standpoint are: graphite, carbides, glass, ceramics and miscellaneous materials such as concrete, ferrites and mica.

Graphite

Many of graphite's mechanical and physical properties are changed when it is irradiated at low temperatures. In general, mechanical properties are improved, the most notable change being an increase in strength and hardness. Thermal and electrical properties, however, decrease after irradiation and some changes occur in the dimensions of finished parts.

The magnitude of radiation effects in graphite depends on the raw materials and fabrication techniques used, as well as on irradiation conditions. All effects decrease in magnitude when the temperature of the material is increased during irradiation. For example, irradiation at 300 F reduces the changes of most physical properties by one order of magnitude compared with those changes incurred by irradiating at 85 F. It is difficult to anneal out the effects of low temperature irradiation. In most cases annealing temperatures on the order of 3600 F are required for complete recovery.

An example of the changes that

TABLE 7—EFFECT OF IRRADIATION ON GLASS

Glass Composition or Type	Type of Radiation or Dosage	Property Change	Remarks
Phosphate Glasses			
K-Ba-Al Phosphate	Gamma	Colors easily	High potassium favors color formation
Ca Metaphosphate	Gamma	Absorption peak near 4700 A	—
Silver (activated)	Gamma	Absorption near UV	Illumination of absorption band causes orange fluorescence
Lead Containing (60 w/o PbO)	10^{14} n/sq cm	No discoloration, melts	—
Special Glasses			
Pure GeO_2 Glass	Gamma	Insensitive at 10^8-10^9 ergs/g(C)	—
1 PbO-1.3 P_2O_5	2 x 10^{20} n/sq cm	Slight discoloration	—
1 PbO-1.22 V_2O_5	2 x 10^{20} n/sq cm	No significant change	—
1 PbO-1.5 SiO_2	2 x 10^{20} n/sq cm	Changes from yellowish clear to amber clear; considerable decrease in hardness	—
0.8K_2O-0.2CaO-2.75 SiO_2	2 x 10^{20} n/sq cm	Changes from colorless to gray	—
$Li_2O \cdot 3B_2O_3$, $Na_2O \cdot 2B_2O_3$, K_2O-$2B_2O_3$, $Rb_2O \cdot 2B_2O_3$	3 x 10^{10} ergs/gm (C), gamma	Absorption 10 times greater than for fused B_2O_3	$Rb_2O \cdot 2B_2O_3$ has highest absorption in visible region
Other Glasses			
Lead Glass (Window)	Gamma	May develop brown coloration	Color removed by annealing 2 to 3 hr at 150 to 200 C
Soft Glass	5.8 x 10^{19} n/sq cm	Dark coloration, slight increase in tensile strength; decrease in impact strength	—
Optical Glass (crown and flint)	10^6-10^8 ergs/gm (C)	Develops color at 10^6 ergs/g (C) or less; useless at 10^8 ergs/gm	—
Optical Glass (protected; containing 1-2% CeO_2)	X-ray or gamma	No coloration at 10^8 ergs/g (C); usable at 5x10^{10} ergs/gm(C)	—
Soda-Lime-Silica Glass (cobalt containing)	Gamma	Color change sensitive to dosage; suitable for dosimeter	—
Fused Silica			
General	All types of high-energy radiation	Color centers form; absorption band at 214 mμ	—
Pure	Fast neutrons	Density may change from 2.2 to 2.27	—
	10^{11} ergs/gm(C), gamma	No change in absorption	—
	Reactor and gamma	Intense absorption band at 218 mμ	Gamma irradiation after reactor exposure increases intensity of absorption band
With Al Impurity	X-ray and UV	Develops absorption bands at 5500, 2950, and 2150 A	—
Borosilicate	10^{20} n/sq cm	Develops large cracks	Cracking presumed to be caused by (n,a) reaction in boron which releases about 3 Mev; formation of a new element hinders annealing
Pyrex (borosilicate)	5.8 x 10^{19} n/sq cm	Color darkens; slight increase in tensile and impact strength	—

can take place by irradiation is provided by an Acheson-type graphite exposed to a fast neutron flux of about 2 x 10^{21} n per sq cm at 86 F. After irradiation the mechanical strength of this material was doubled, its thermal conductivity increased fifty-fold, its dimensions increased by over 3%, and it accumulated more than 500 cal of stored energy per gm (*Woods et al.*).

The radiation effects in diamond appear to be quite similar to those observed in graphite. However, in contrast to graphite, the structure of many carbons tends to become more ordered when irradiated and increases in electrical and thermal conductivity have been noted.

Carbides

Changes in the crystal dimensions, density, and thermal and electrical properties of carbides have been found at high radiation exposures. Boron carbide, for example, irradiated to 3 x 10^{20} n per sq cm exhibits a 0.63% expansion in a_o and a 0.83% contraction in c_o. Some fragmentation and formation of lithium and helium in the lattice of the material have also been noted.

Some expansion can also be expected with silicon carbide materials. After exposure to 1 x 10^{20} n per sq cm, hexagonal silicon carbide exhibits an expansion of 0.3% and cubic silicon carbide shows a growth of 0.76%. However, these changes can be substantially annealed out at 2190 F *(Johnson)*.

Glass

Radiation colors most glasses. In most cases coloration occurs at gamma doses as low as 100 ergs per gm (C) and saturation occurs at 10^{12} ergs per gm (C). Physical disintegration may take place at higher exposures.

Some of the systems that help to prevent or decrease loss of light transmission are the use of transparent shielding materials containing lead oxide, and the addition of 1 to 2% tetravalent cerium in the batch composition of the glass. Tetravalent cerium is apparently an electron acceptor and removes free electrons that would otherwise form color centers.

A summary of the effects of radiation on a wide range of glasses is given in Table 7. Although some physical properties of glass are sensitive to irradiation, low temperature neutron irradiation affects such properties as density and thermal conductivity to a lesser degree than most ceramics. Like ceramics, radiation damage to glass depends on the temperature of irradiation and it can be readily annealed out by heat treatment.

Radiation will create color changes in quartz as well as causing changes in thermal and electrical conductivity, index of refraction and elastic properties. Under irradiation, high-grade natural quartz changes from a clear, uncolored appearance to a uniform gray. This color change is related to impurity content in the material.

Ceramics and allied materials

Irradiation causes many property changes in ceramics, and the magnitude of these changes is intimately dependent on raw materials and methods of fabrication. The threshold of damage of ceramic materials of moderate stability appears to occur at about 10^{17} n per sq cm. However, property changes are small at integrated fluxes of 10^{18} n per sq cm and at the type of neutron energy spectrum present in a graphite-moderated reactor. Damage in many (if not all) ceramics is mihimized by irradiation at elevated temperatures. Also, physical property changes can generally be annealed out after irradiation.

A summary of the effects of irradiation on commonly used ceramics and related inorganic nonmetallics is given in Table 8.

TABLE 8—EFFECT OF IRRADIATION ON CERAMICS AND ALLIED MATERIALS

Material	Exposure	Effects
CERAMIC OXIDES		
Al_2O_3[a]	2×10^{70} n/sq cm	No change in x-ray pattern and thermal conductivity. Some color change, probably F-center phenomena
	10^9 ergs/gm (C), gamma	Color change, F-centers
BeO[b]	2×10^{20} n/sq cm	0.3% expansion in c_0, none in a_0 as determined by x-ray pattern. No change in thermal conductivity
MgO[c]	2×10^{20} n/sq cm	No change in basic lattice. Single crystal broken into reactive small crystals
	10^9 ergs/gm (C), gamma	Blue color, F-center formation
Quartz	10^{21} n/sq cm	Decrease in density to 2.25. Change in axial ratio (c/a) from 4.1 to about 1.06 at this dosage; two macroscopic roles parallel to c-axis form on annealing at 1740 F. Density changes annealed out at 1830 F. Significant energy release shown by DTA at 1110 F
SiO_2	10^{21} n/sq cm	Decrease in density to about 2.25 (17.7% change). No macroscopic defects or loss of structure. Color changes, F-centers
SiO_2[d]	2×10^{20} n/sq cm	Increase in density to 2.25. Heating at red heat removes increase. F-center color changes to deep violet or dark brown
	2×10^{10} ergs/gm (C), electrons	Highly purified silica shows no discoloration. Commercial silica appears dark and mottled
TiO_2[e]	2×10^{20} n/sq cm	No change in x-ray pattern. Slight decrease in thermal conductivity. Color change
ZrO_2[e]	2×10^{20} n/sq cm	Radiation-induced phase change, monoclinic to cubic. No change in cubic lattice. Slight decrease in thermal conductivity
MISCELLANEOUS CERAMICS		
Spinel ($MgO \cdot 3.5\ Al_2O_3$), Forsterite, Porcelain, Steatite	2×10^{20} n/sq cm	No change in crystal structure. Decrease in thermal conductivity (factor of 2). Color change, F-centers
	10^9 ergs/gm (C), gamma	Color change, F-centers
Cordierite	2×10^{20} n/sq cm	Loss of crystallinity. Decrease in thermal conductivity (factor of 4). Color change, F-centers
Zircon	1×10^{20} n/sq cm	1.9% expansion. Large loss of crystallinity
	2×10^{20} n/sq cm	Complete loss of crystallinity. Decrease of thermal conductivity (factor of 5). Color change
	10^9 ergs/gm (C), gamma	Color change, F-centers
$BaTiO_3$	2×10^{20} n/sq cm	2.87% expansion in a_0. Marked color change
	10^9 ergs/gm (C), gamma	Color change, F-centers
Mica (Muscovite)	10^9 ergs/gm (C), gamma	No effects noted

[a]Effects noted on both single crystals and hot pressed materials.
[b]Hot pressed.
[c]Single crystal.
[d]Vitreous.
[e]Polycrystalline, sintered.

Ceramic oxides—Preliminary results indicate that irradiation at 3×10^{18} n per sq cm causes no permanent effects on the properties of aluminum and magnesium oxide. However, it has been found that the thermal conductivity of aluminum oxide increases greatly in a nuclear reactor field at 750 F (*Monk*).

Minerals—The most radiation resistant minerals are the oxides such as corundum, spinels, zircons, etc., which have a simple crystalline structure. Although these minerals would be expected to show an increase in hardness and density, present evidence indicates that they are little damaged at exposures up to 10^{18} fast n per sq cm.

Mica—It has been reported that some degree of electrical conductivity is induced in mica by gamma radiation. Also, mica sheet has been found to bend after strong ionizing radiation.

Ferrites—Gamma radiation can produce a temporary increase in the electrical conductivity of ferrites. However, normal properties are restored very quickly (a matter of minutes) at room temperature.

Barium titanate—Barium titanate exhibits a change in dielectric constant when irradiated at 2×10^{20} n per sq cm. Normally this material exhibits a peak in the dielectric constant versus temperature curve. However, irradiation essentially causes this peak to disappear and reduces dielectric constant to a nearly constant value over the temperature range of 85 to 285 F (*Rogers*).

Concrete—Irradiation tends to reduce the water content of concrete and reduce its breaking strength. Magnesium oxychloride concrete, for example, has shown as much as an 80% decrease in compressive strength after being irradiated to about 3×10^{18} n per sq cm (*Lyon*).

Elastomers

vary widely in radiation resistance

In analyzing the effects of irradiation on elastomers the engineer should realize that the recipe of a specific material may vary, and that different conditions of irradiation may have been used from test to test. Consequently, values may not be consistent.

Several methods are available for improving the radiation resistance of elastomers. These include the use of fillers, addition of radiation-resistant resins, and the use of organic additives called antirads. In general, carbon black fillers are superior to mineral fillers. Resins have been used to improve the radiation resistance of gum stocks but appear to have little effect on black stocks.

A number of antirads have been found that will extend the retention of tensile strength and the ultimate elongation of natural rubber tread stocks by a factor of ten after irradiation. The best antirad, N,N'-cyclo-hexylphenyl-para-phenylenediamine, has enabled a rubber compound to retain 99% of its initial tensile strength and 88% of its ultimate elongation after irradiation at 10^{10} ergs per gm (C). By comparison, values of 36 and 18%, respectively, are exhibited by the normally protected control rubber compound. Table 9 lists ten of the better antirads, based on their ability to retain tensile strength and elongation. Also, the decreasing resistance of elastomers to radiation is presented graphically in Fig 2.

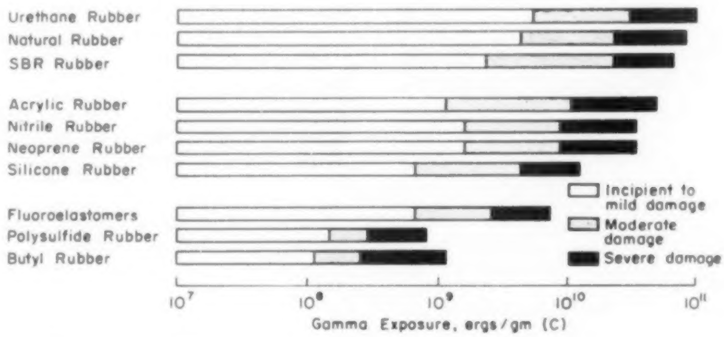
Natural rubber

Irradiation of natural rubber induces crosslinking and tends to decrease elastic properties and increase hardness. This is similar to the effects of over-vulcanization whereby natural rubber acquires a rigidity comparable to glass.

Natural rubber is unaffected by radiation up to about 2×10^8 ergs per gm (C). Damage of 25% for overall properties accrues at approximately 2.5×10^9 ergs per gm (C). Tensile strength is not affected until the rubber is exposed to 2.4×10^9 ergs per gm (C) and 25% damage is incurred at a level of 1.5×10^{10} ergs per gm (C). Elongation and set-at-break are not affected up to about 5.5×10^8 ergs per gm (C).

Polyurethane rubber

Studies indicate that the radiation resistance of polyurethane rubbers is equal to or better than natural rubber (*Harrington*).



2 Relative stability *of elastomeric materials to irradiation.*

TABLE 9—RELATIVE RATING OF ANTIRADS BASED ON STRESS-STRAIN PROPERTIES[a]

Relative Rating[b]	Antirad	% of Initial Value	
		Tensile Strength	Elongation
1	N, N'-Cyclohexylphenyl-p-phenylenediamine	90	88
2	35% Diphenyl-para-phenylenediamine, plus 65% Phenyl-alpha-naphthylamine	86	76
3	Quinhydrone	91	74
4	N-p-tolyl-N'p-toluenesulfonyl-p-phenylenediamine	91	70
5	N-phenyl-N'-o-tolylethylenediamine	83	72
6	Beta-naphthol	85	71
7	Beta-naphthylamine	85	70
8	20 CC 59A	72	82
9	Pyrogallol	100	66
10	Phenyl hydroquinone	87	68
11	N, N'-Dioctyl-para-phenylenediamine	82	69
89	ASTM Natural Rubber Tread Stock Control	36	18

[a]Total radiation exposure: 10^{10} ergs per gm (C). (*Loughborough, et al*).
[b]Low numbers are best.

TABLE 10—EFFECT OF IRRADIATION ON PROPERTIES OF FLUOROCARBON ELASTOMERS[a]

Material	Dose, ergs/gm (C)	Initial Properties and Change After Irradiation						Remarks
		Hardness		Elongation		Tensile Strength		
		Shore A	Change, %	%	Change, %	Psi	Change, %	
Viton A-7	0	88	—	250	—	2270	—	Gray-brown
	8.7×10^9	—	12.5	—	−94	—	6.8	[b]
Viton A-8	0	79	—	180	—	2285	—	Tan
	8.7×10^9	—	22.8	—	−88.9	—	−1	[b]
Viton A-9	0	78	—	165	—	1810	—	Tan
	8.7×10^9	—	24.4	—	−84.7	—	46.3	[b]
Viton A-10	0	77	—	140	—	1765	—	Brown
	8.7×10^9	—	23.4	—	−85.7	—	12.4	[b]
Viton A-11	0	79	—	125	—	2095	—	Dark gray
	8.7×10^9	—	24.1	—	−80.3	—	27.9	[b]
Pr 1710-X69	0	74	—	180	—	1525	—	Black
	8.7×10^9	—	23	—	−86.1	—	18.5	[b, c]
Kel-F 5500	0	62	—	550	—	1810	—	Gray
	8.7×10^7	—	0	—	9.1	—	44.2	—
	4.4×10^8	—	0	—	−8.2	—	19.6	—
	1.9×10^9	—	3.2	—	−41.8	—	−28.8	[c]
	4.8×10^9	—	16.1	—	−73.6	—	−24.9	[d]
	8.7×10^9	—	25.8	—	−80	—	−13.9	[c]

[a] *Harrington.*
[b] Broke when bent 180 degrees.
[c] Slightly tacky.
[d] Glossy on surface, quite tacky.

They are not affected up to 9×10^7 per gm (C), but are damaged by about 25% at approximately 4×10^8 ergs per gm (C). In general, urethane elastomers tend to soften at exposures up to 4×10^{10} ergs per gm (C), and then become increasingly harder. The materials tend to decrease in both tensile strength and elongation after irradiation. Compounding appears to have little effect on radiation resistance for most types.

Styrene-butadiene (SBR) rubber

Styrene-butadiene rubber (SBR), commonly called GR-S or tire rubber, resists radiation better than any of the synthetic rubbers, but it is not equal to natural rubber in radiation resistance. Threshold damage is reached at 2×10^8 ergs per gm (C), and 25% damage accrues at 1×10^9 ergs per gm (C).

Tensile strength of the material changes less rapidly than that of natural rubber. For example, tensile strength does not decrease by 25% until about 3×10^{10} ergs per gm (C), as compared to 1.5×10^{10} ergs per gm (C), for natural rubber (*Bopp and Sisman*). However, other properties of the material, such as elongation, set-at-break and compression set, decrease by 25% at 1.5×10^9 ergs per gm (C). Additions of Hycar HH (a brominated butyl rubber that is more compatible than ordinary butyl rubber) to SBR can be used to delay radiation damage.

The rate of property changes for both hot SBR (polymerized at 122 F or higher) and cold SBR (polymerized at 41 F) is about the same under irradiation (*Loughborough et al.*). Cold SBR has better initial physical properties than hot SBR and this superiority is evident after irradiation.

Nitrile rubber

Nitrile rubber (NBR) is a copolymer of acrylonitrile and butadiene. Formulations with a high acrylonitrile content have about average radiation stability compared to other elastomers. Compression set degrades by about 25% at 7×10^8 ergs per gm (C). Tensile strength is variable after irradiation and increases by 25% at 1.5×10^{10} ergs per gm (C).

Neoprene rubber

In general, the properties of neoprene (polychloroprene) rubber are similar to nitrile rubber after irradiation. Neoprene W retains its Shore hardness under greater radiation doses than do the other elastomers, its hardness being unaffected up to 4.5×10^9 ergs per gm (C). However, hardness increases rapidly above this dose, increasing by 10 Shore units by the time a level of 1.5×10^{10} ergs per gm (C) is reached.

Hypalon (chlorosulfonated polyethylene)

It is difficult to predict the tensile strength of Hypalon, because the material exhibits different trends during irradiation. In some cases the material retains nearly its original value up to 9×10^9 ergs per gm (C), after which it starts to increase with higher dosages. In other cases, tensile strength increases at low doses, drops considerably at about 4.5×10^9 ergs per gm (C), and then starts to increase with continued exposure.

Continued exposure tends to increase the hardness and decrease the elongation of Hypalon (*Harrington*). Data suggest that stability can be improved by adding

aromatic plasticizers such as Kenflex A.

Acrylic rubber

Acrylic, or polyacrylate, rubbers are based on polymers of butyl or ethylacrylate. Both types of polymers appear to behave similarly when irradiated. They undergo slight amounts of crosslinking and chain cleavage when exposed at 9 x 10^9 ergs per gm (C). Their hardness increases with increasing exposure. However, their tensile strength behaves erratically. It increases or decreases after short exposure, remains relatively unchanged for intermediate exposure, and then drops and eventually increases with prolonged exposure.

Silicone rubber

In general, the radiation resistance of silicone rubbers is below the average of other elastomers. Physical properties are damaged by 25% at exposures less than 10^9 ergs per gm (C).

Fluorocarbon rubber

Fluorocarbon rubbers have been found to be very sensitive to radiation. Indications are that the materials undergo both crosslinking and chain cleavage when irradiated. As shown in Table 10 fluorocarbon rubbers exposed to 9 x 10^9 ergs per gm (C) increase about 25% in hardness and lose about 80% of their elongation. Tensile strength also varies. Viton A compositions show an increase of 7 to 45%. Kel-F 5500's tensile strength increases by 44% at low doses and then drops 14% below its original value as dosage is increased to 9 x 10^9 ergs per gm (C).

Indications are that the stability of fluorocarbon rubbers is quite dependent on the environment. Thus, the stability of the materials in air cannot be used to predict their stability in other media. For example, Viton A remains stable at 10^{10} ergs per gm (C) in diester oil at 400 F, but retains its stability only to 6 x 10^9 ergs per gm (C) in air at room temperature. Similarly, Kel-F irradiated at room temperature to 10^{10} ergs per gm (C) in silicate ester fluids remains stable, but retains its stability only to 6 x 10^8 ergs per gm (C) when irradiated in air.

Polysulfide rubber

The hardness of polysulfide rubber does not change significantly up to 2.5 x 10^{10} ergs per gm (C). However, tests conducted at 4.5 x 10^{10} ergs per gm (C) have caused such great damage that hardness could not be measured (*Harrington*). Also, at the higher exposure, both elongation and tensile strength were reduced to zero, suggesting that the material may undergo chain cleavage. No stress cracking was observed at either exposure.

Butyl rubber

In general, butyl rubber appears suitable for use only at relatively low radiation doses. The tensile strength of the material decreases with increasing irradiation. A damage level of 25% is reached for hardness at about 5 x 10^9 ergs per gm, and for tensile strength and elongation at about 10^9 ergs per gm. The material shows no evidence of stress cracking after irradiation.

Plastics

generally have equal or better radiation resistance than elastomers

In general, the radiation resistance of plastics is equal to, or better than, elastomers. The plastics with the highest resistance to radiation include: polystyrene, mineral-filled phenolics and polyesters, phenolic laminates, polyethylene, polyethylene terephthalate, polyvinyl chloride, epoxies and glass-reinforced silicones (see Fig 3). These materials are unaffected at doses varying from 10^9 to 10^{11} ergs per gm (C), and are changed by 25% at doses varying from 10^{10} to 10^{11} ergs per gm (C).

Plastics with intermediate radiation resistance include: melamine-formaldehyde, unfilled phenol-formaldehyde and urea-formaldehyde. These materials are unaffected by 10^8 to 10^9 ergs per gm (C) and are damaged 25% by dosages over 10^9 to 10^{10} ergs per gm (C).

The poorest radiation stability is exhibited by the cellulosics, polyamides, Teflon, and unfilled polyesters and silicones. Damage to these plastics occurs in the range of 10^6 to 10^8 ergs per gm (C) and they are damaged by 25% at dosages ranging from 3 x 10^6 to 6 x 10^8 ergs per gm (C).

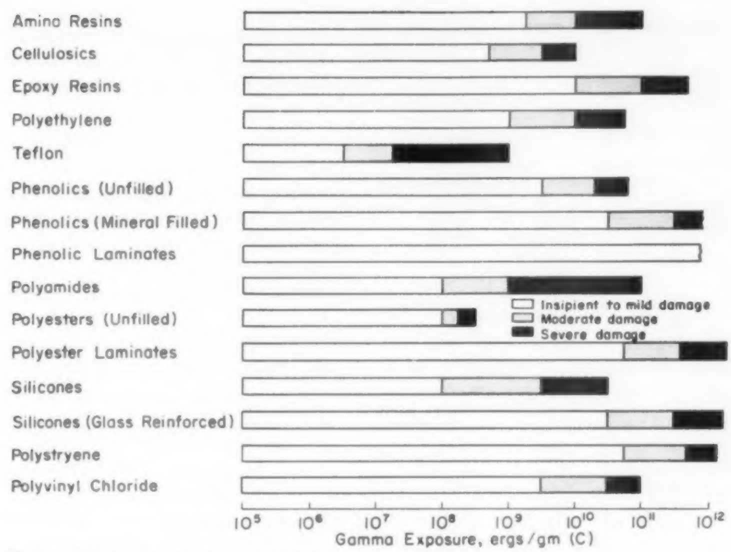
Amino resins

This group of resins comprises urea-, melamine- and aniline-formaldehyde. The radiation resistance of urea-formaldehyde is about average for plastics. The material is unaffected up to 8.5 x 10^8 ergs per gm (C) and is damaged by 25% at 5.1 x 10^9 ergs per gm (C).

Melamine-formaldehyde has slightly better radiation resistance, being unaffected up to 7.5 x 10^8 ergs per gm (C) and damaged by 25% at 10^{10} ergs per gm (C). When filled with cellulosic materials, both urea- and melamine-formaldehyde become brittle, blister, swell, and crumble on exposure to gamma radiation.

Cellulosics

Cellulosic polymers such as cellulose acetate, cellulose acetate butyrate, cellulose nitrate, cellulose propionate, and ethyl cellulose are among the least radiation-resistant plastics materials. Their physical properties (except breakdown voltage) deteriorate rapidly under gamma radiation. Cellulose acetate, considered to be one of the more radiation-resistant cellulosics, suffers 25% damage at a dose of 2 x 10^9 ergs per gm (C).

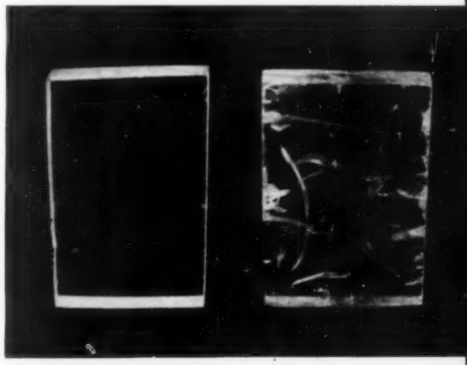


3 ***Relative stability*** *of plastics to irradiation.*

Rubber o-ring

Organic materials: before and after irradiation

Chlorinated polyether gasket



Polystyrene sheet

Epoxies

Epoxy resins have comparatively high resistance to radiation and do not deteriorate at doses up to 9.5×10^{10} ergs per gm (C). Their radiation stability is greatly affected by the curing system and reactive diluent used (*Colichman* and *Strong*). Best radiation resistance is obtained with aromatic-type curing agents such as m-phenylenediamine and pyromellitic dianhydride. Such systems are stable to at least 10^{10} ergs per gm (C), the maximum exposure to which the materials have been subjected.

Best radiation resistance is exhibited by epoxies with high distortion temperatures (such as those cured with pyromellitic dianhydride). Based on limited studies, epoxy-phenolic systems also have very good radiation stability and maintain their properties up to 10^{11} ergs per gm (C).

Polyethylene

Polyethylene is unaffected by radiation at 2×10^9 ergs per gm (C) and accrues 25% damage at 9×10^9 ergs per gm (C). At doses greater than 10^9 ergs per gm (C) the material starts to become flexible and rubber-like. With continued exposure it becomes a crosslinked material that is somewhat brittle and cheesy. Although the tensile strength of polyethylene increases with initial irradiation, it begins to decrease at about 10^{10} ergs per gm (C) and becomes 25% lower than its initial value at about 10^{12} ergs per gm (C).

Polyethylene films show considerable property changes between 4×10^8 and 9×10^8 ergs per gm (C). The fact that the material is subject to oxidation during irradiation may explain why thin films are degraded at lower doses than heavier sections.

Polyethylene containing carbon black and an oxidant appears to have slightly better tensile strength but poorer elongation than standard polyethylene. One high density material exposed at 8×10^9 ergs per gm (C) shows an increase in tensile strength, a drop in elongation, and some brittleness. Thus, it appears that the high density material is slightly more resistant than standard polyethylene, but not enough to make it more serviceable.

Fluoroethylene polymers

Fluoroethylene polymers are highly susceptible to radiation damage. A fluorinated material does not crosslink; instead, the fluorine atom is liberated and reacts to break a carbon-to-carbon bond. This contributes to poor radiation resistance.

Teflon is one of the least radiation-resistant plastics. However, because of its exceptionally good heat and chemical resistance, it is desirable for applications where relatively low radiation exposures are anticipated. Threshold damage for the material is about 2×10^6 ergs per gm (C), and 25% damage occurs at about 3.5×10^6 ergs per gm (C) (*Collins* and *Calkins*). Exposures may be increased in some applications, particularly in contact with oils.

TABLE 11—EFFECT OF IRRADIATION ON PROPERTIES OF PLASTICS LAMINATES*

Material ↓	Irradiation			Ult Str, psi	Flexural Mod, 10^6 psi
	Exposure, ergs/gm (C)	Temp, F	Exposure Time, hr		
Silicone (flexure test)	None	Room	None	31,760	3.06
	8.5 x 10^9	Room	200	31,460	2.94
	None	500	50	12,390	1.90
	2 x 10^9	500	50	13,625	2
	None	500	100	13,410	2
	4 x 10^9	500	100	11,720	2
	None	500	200	14,060	2
	8.5 x 10^9	500	200	9,860	1.9
Heat Resistant Epoxy (compression test)	None	Room	None	46,680	—
	8.5 x 10^9	Room	200	46,660	—
	None	500	50	3,705	—
	2 x 10^9	500	50	3,780	—
	None	500	100	4,090	—
	4 x 10^9	500	100	5,490	—
	None	500	200	4,720	—
	8.5 x 10^9	500	200	6,360	—
Phenolic (flexure test)	None	Room	None	84,525	4.22
	8.5 x 10^9	Room	200	84,040	4.35
	None	500	50	27,300	3.14
	2 x 10^9	500	50	55,020	3.46
	None	500	100	17,660	2.62
	4 x 10^9	500	100	47,015	3.61
	None	500	200	12,330	2.13
	8.5 x 10^9	500	200	15,645	2.41

*Keller.

Phenolics

Unfilled phenolics have relatively poor radiation resistance; under irradiation they swell, become brittle and crumble. Damage of 25% occurs at 10^9 ergs per gm (C), and tensile and impact strengths of the materials drop off about 50% at 3 x 10^{10} ergs per gm (C). Also, a soluble product is formed during irradiation which causes the materials to disintegrate in water (*Sisman*).

Radiation stability can be increased by adding fillers, particularly mineral fillers. Phenol-formaldehyde with an asbestos filler shows excellent stability and is one of the more radiation-resistant plastics, possibly because of its relatively high heat stability. It is unaffected by radiation exposures of more than 4 x 10^{10} ergs per gm (C).

Phenolic laminates have been exposed to 8.5 x 10^{11} ergs per gm (C) at room temperature without reaching threshold damage. As shown in Table 11, laminates irradiated to 2 x 10^9 ergs per gm (C) at 900 F for 50 hr have shown flexural strength equivalent to unirradiated laminates also exposed to 900 F for 50 hr.

Polyamides

Nylon loses its crystallinity at about the same dose as polyethylene, 10^9 ergs per gm (C), and as a result of this loss in crystallinity it becomes more transparent. Nylon crosslinks when irradiated, but does not harden or become brittle as fast as polyethylene.

Nylon fiber shows a rapid loss in strength when irradiated in air. Conversely, the tensile strength of nylon sheet increases with irradiation, in a manner similar to polyethylene (*Sisman* and *Bopp*).

Nylon sheet reaches threshold damage at 9 x 10^7 ergs per gm (C), and 25% damage at 5 x 10^8 ergs per gm (C). Tensile strength increases 25% at about 10^{11} ergs per gm (C). However, elongation (and impact strength) decreases very rapidly, changing by 25% at about 5 x 10^8 ergs per gm (C).

Polyesters

Unfilled polyesters have poor radiation resistance and tend to harden and develop small cracks during exposure. Although their radiation stability varies somewhat, properties begin to change between 10^7 and 10^8 ergs per gm (C). Both tensile and impact strengths decrease, although tensile strength may increase at first.

Allyl diglycol carbonate (used as a casting resin or adhesive) is one of the more radiation-resistant polyesters. It is unaffected up to 1.5 x 10^8 ergs per gm (C), and is damaged by 25% at 9 x 10^9 ergs per gm (C). Elongation of this material increases to a maximum of more than 250% at 5.5 x 10^{10} ergs per gm (C) and then decreases rapidly.

The radiation stability of polyesters can be increased up to 100-fold by adding mineral fillers. One mineral filled alkyd, for example, doesn't show any change in physical properties until about 10^{10} ergs per gm (C), as compared to 10^7 or 10^8 ergs per gm (C) for the unfilled material (*Sisman* and *Bopp*). Deterioration of 25% of the filled alkyd is attained at 4 x 10^{11} ergs per gm (C) after which properties decrease rapidly.

Irradiation of Mylar polyester film produces no change in tensile strength and elongation at doses up to 3 x 10^9 ergs per gm (C). However, the film does darken and become brittle after irradiation (*Sisman* and *Bopp*).

Silicones

Silicones show a wide variation in radiation stability. The presence of phenyl groups in the silicone chain increases radiation stability, and the presence of methyl groups increases flexibility. Since silicone resins generally have a phenyl content they have reasonably good radiation resistance.

The radiation stability of silicone resins is improved when they are reinforced with glass fibers. Glass-reinforced silicone lamin-

ates reach threshold damage at about 10^{11} ergs per gm (C) at room temperature. However, tensile strength does not drop off until 2.5 x 10^{11} ergs per gm (C) (*Keller*).

Asbestos-silicone laminates show no apparent change in properties up to 1 to 2 x 10^{10} ergs per gm (C). Tests made at 6 x 10^{10} ergs per gm (C) show a drop in tensile strength of 10%, a decrease in shear strength of 5%, and a 5% increase in both hardness and specific gravity.

Polystyrene polymers and copolymers

In terms of change in physical properties and hydrogen evolution, polystyrene is one of the most radiation resistant plastics. Polystyrene's stability is believed to be due to the dissipation of radiation energy in the benzene ring structure. It undergoes threshold degradation at 10^{10} ergs per gm (C) and 25% damage at doses greater than 4 x 10^{11} ergs per gm (C). Exposure at 10^{12} ergs per gm (C) appears to start a wholesale disruption of the polystyrene molecule (*Billinton*). Although there appears to be a post-irradiation oxidation effect on the material, the effect of this phenomenon on physical properties is not understood.

Styrene copolymers generally have poorer radiation stability than styrene polymers. For example, SBR, a copolymer of styrene and butadiene, is less resistant to radiation than polystyrene. Also, modified high impact strength styrenes lose their impact strength rapidly when irradiated until they are no better than modified polystyrenes. This indicates that the modifying agent is affected rather than the polystyrene itself.

Vinyl polymers and copolymers

Because of the variety of vinyl compositions that are available it is not surprising that their radiation resistance varies over a wide range.

Polyvinyl carbazole is one of the most radiation-resistant plastics. It has a threshold damage of 9 x 10^{9} ergs per gm (C) and is damaged 25% at about 4.5 x 10^{11} ergs per gm (C). However, applications of the material are limited because of its brittleness. Polyvinyl carbazole is affected at doses lower than those that affect polystyrene, but both materials are damaged 25% at about the same dose.

Polyvinyl chloride (PVC) has about the same radiation stability as polyethylene. Its properties begin to change at 2 x 10^{9} ergs per gm (C); it is damaged by 25% at 10^{10} ergs per gm (C). The liberation of hydrogen chloride during irradiation makes the material unsuitable for many applications in a nuclear environment.

Polyvinyl butyral is unaffected by radiation at 5 x 10^{8} ergs per gm (C). Upon irradiation, the material first softens and then becomes more brittle (*Bopp* and *Sisman*). Its tensile strength decreases rapidly after 10^{9} ergs per gm (C), and 25% damage accrues at a level of 2 x 10^{9} ergs per gm (C).

Polyvinyl formal is similar to polyvinyl butyral in its properties and applications. However, its radiation resistance is better than the butyral, but slightly poorer than PVC. It has a threshold damage of 1.5 x 10^{9} ergs per gm (C), and 25% damage occurs at 8 x 10^{9} ergs per gm (C).

Polyvinylidine chloride (saran) softens, becomes black, evolves hydrogen chloride, and decreases in tensile strength when irradiated (*Javitz*). Its threshold damage is 4 x 10^{8} ergs per gm (C), and 25% damage occurs at 4.5 x 10^{9} ergs per gm (C).

Vinyl chloride acetate behaves like saran when irradiated. Threshold damage is reached at 1.5 x 10^{8} ergs per gm (C), and it is damaged 25% at a level of 3 x 10^{8} ergs per gm (C). It turns black after a very short period of irradiation. However, even before changing color it starts to soften and elongation increases by well over 500% before a dose of 5 x 10^{8} ergs per gm (C) has been reached (*Javitz*).

How About Electrical and Electronic Components?

Semiconductor devices in general are more susceptible to radiation damage than most other electronic components. Their use in a stringent nuclear environment (say 10^{11} to 10^{15} fast n per sq cm) causes many problems such as: permanent damage produced by fast neutrons, induced voltages produced by ionizing radiation, and high ambient temperatures.

Electron tubes having hard borosilicate glass envelopes are not suitable in a radiation field because fractures develop in the glass. Otherwise, tube operation does not appear to be affected by exposure to 10^{15} fast n per sq cm. Ceramic encased tubes appear capable of operation at high temperatures and may be radiation resistant. However, these tubes are difficult to produce. Photo-tubes develop a transient background current dependent on radiation intensity.

Capacitors containing ceramic, glass, mica and Mylar can be used at fast neutron exposures of 10^{15} n per sq cm and gamma exposures of 10^{11} ergs per gm (C). Plastic, electrolytic, and oil-filled or oil-impregnated capacitors are extremely susceptible to radiation. Oil-filled capacitors degrade by oil leakage and gas evolution in the neighborhood of 10^{13} fast n per sq cm.

Resistors of the wire wound, carbon composition and film types are generally suitable in a radiation environment of 10^{15} fast n per sq cm and 10^{11} ergs per gm (C).

Electrical insulation failures in nuclear radiation environments are primarily due to physical and mechanical deterioration of the materials rather than to gross changes in their dielectric properties.

Printed circuit boards are subject to serious degradation in a radiation environment. Depending on the type of boards used, they exhibit deterioration of the base material, development of leakage paths; and loosening and corrosion of the conductor strips and terminals.

Organic fluids

can have composition adjusted to provide compromise of properties

Lubricants

The radiation tolerance of gas turbine lubricants ranges from 10^9 to 10^{11} ergs per gm (C). Although polyphenyl ethers show very good radiation resistance, it appears that hydrocarbon fluids such as highly refined mineral oils and alkyl aromatics may offer the best compromise of stability (radiation, oxidation and thermal), lubricity and low temperature performance. Limited data indicate that for each fluid there exists a critical gamma exposure below which radiation exerts little or no effect. With some hydrocarbon fluids this exposure may be greater than 10^{10} ergs per gm (C).

Fuels

Various tests on commercial jet fuels show that their radiation tolerance is about 10^{10} ergs per gm (C). The effect of irradiation on the thermal stability of jet fuels is particularly important. Indications are that saturate petroleum fractions and synthetic fuels have the best stability.

Hydraulic fluids

Polyphenyl ethers show outstanding stability [10^{11} ergs per gm (C)] for high temperature applications where pour point is not critical. Alkyl diphenyl ethers have slightly lower pour points but are somewhat less stable than the unsubstituted polyphenyl ethers. As with lubricants, alkyl aromatics may offer the best balance in pour point and stability.

Heat transfer fluids

The terphenyls show the highest radiation resistance and are recommended over other heat transfer materials for high radiation exposures. Of the terphenyls, the para isomers show the greatest resistance at low exposure. At higher exposure the three isomers approach one another in stability.

Monoisopropylbiphenyl, biphenyl, diphenyl ether and silicate esters also appear to possess good radiation stability. Ethylene glycol, chlorinated diphenyls, DC-710 silicone, and phosphate esters are resistant to about 8.5 x 10^9 ergs per gm (C).

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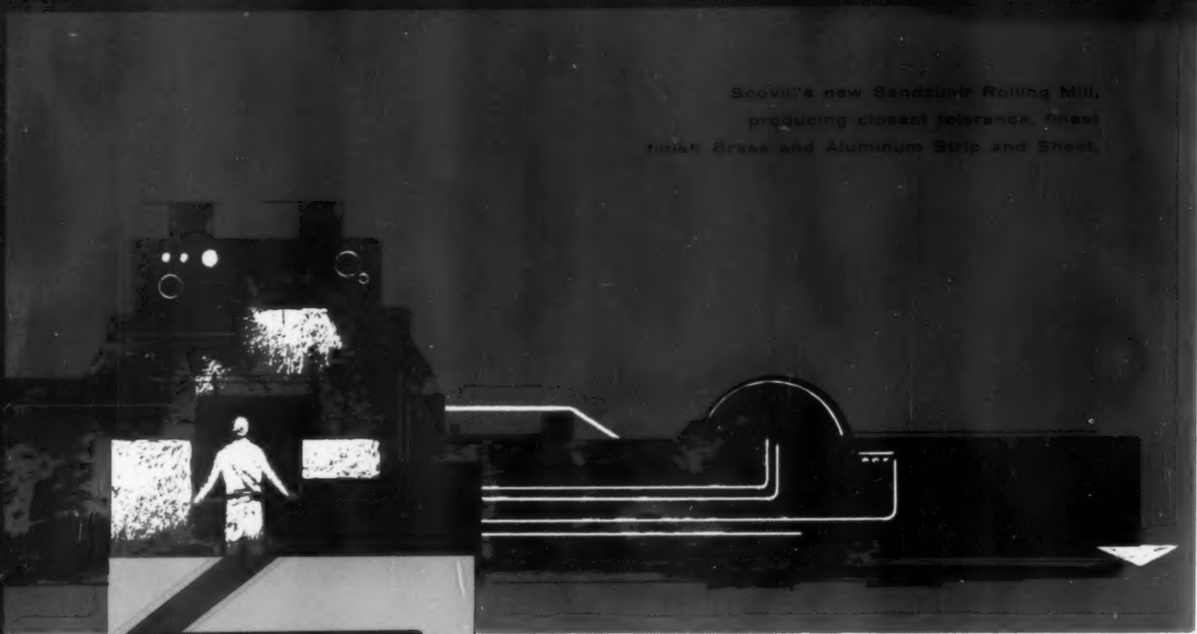

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FILE FACTS

Some Leather Materials

(Listed by Intended End-Use)[a]

Class, Grade, Type, Tannage	Unit, Finish, Special Requirements, Selection
Automotive, Military Cattlehide, Chrome Tanned Strap Pad and Reinforcement (MIL-L-3754) Type I—Full Grain Leather Grade A—High Strength Grade B—Medium Strength Type II—Split Leather	Unit: Strap, buckle pad, reinforcement; large piece. Finish: Type I—Full grain or slightly snuffed. Type II—Smooth, firm surface. Retan leather may be used subject to approval of purchaser. Flexibility of Type I: 1 in-lb max; for ½ in. span, 60-deg bend. To maintain reasonable flexibility at −65 F. Shrinkage: Type I—5% max; Type II—10% max. Mold resistance: Treatment according to MIL-L-10331; no mold growth in 95% or higher RH
Bags, Briefcases Cattlehide, Vegetable Tanned (KK-L-154) Type I—Bag Leather Type II—Case Leather	Unit: Side. Finish: Full grain or corrected; smooth, boarded, or embossed in fine or coarse grain. Area: 18 sq ft min. Mold resistance: Condn A—treated; Condn B—untreated. Crocking resistance: Good. Selections: A—Free of defects; B—6% cutting loss; C—12% cutting loss
Belting—Flat for Power Transmission Cattlehide (no bull or stag), Vegetable Tanned (KK-B-201) Type I[b] Class 2—Medium (10-11.5 oz) Class 3—Heavy (12-14 oz) Type II[c] Class 1—Light (17-18.5 oz) Class 2—Medium (19-20.50 oz) Class 3—Heavy (21-24 oz)	Unit: Strip (from belting butt). Finish: Smooth unpolished (no stretcher marks). Mold resistance: Condn A—treated; Condn B—untreated. Defects (grub holes) to be specified. Thickness tolerances: Type I, +3/64, -2/64 in.; Type II, +2/64 in. Curvature of joined strips: ½ in. max. No piping over mandrels as follows: Type I, Classes 2 and 3—3 in.; Type II, Class 1—4 in.; Class 2—6 in.; Class 3—8 in. Cementing type: waterproof
Packings, Hydraulic Cattlehide, Chrome Tanned (MIL-L-13188) Type I—Selected Pieces Class 1—Nonimpregnated Type II—Formed Leather Parts Class 1—Nonimpregnated Class 2—Impregnated	Unit: Piece or formed part from belting butt. Finish: Full grain. Impregnation as specified. No hard spots or grit. Noncorrosive to metal. Shrinkage: 5% max. No wrinkling after cracking and hand flattening to original state. Moldability, of Type I only, to be tested to purchaser's directions. Analysis: Soluble chlorides—0.30% max; soluble sulfates—0.30% max
Packings, Hydraulic Cattlehide, Mineral Tanned (KK-L-163) Type I—Regular Type II—Noncorrosive	Unit: Belting butt bend. Finish: Full grain. Shrinkage: 5% max. Analysis: Soluble chlorides—0.30% max; soluble sulfates—0.30% max. Selections: A—free of defects; B—6% cutting loss; C—12% cutting loss
Packings, Hydraulic (use temp not to exceed 175 F) Cattlehide, Chrome-Vegetable Retanned (KK-L-231) Light (7-10 oz) Medium (10-13 oz) Heavy (13+oz)	Unit: Bend, or belting butt bend. Finish: Full grain. Shrinkage on treatment with gasoline, 2%; oil, 15%; air, 5%; water, 5%. Selections: A—free of defects; B—each unit, 1 brand (100 sq in.). 25% of units with 3 surface scratches (15 in. max), 15 healed grub holes
Packings, Gaskets (use temp not to exceed 122 F) Cattlehide, Vegetable Tanned (KK-L-157) Light, Medium, or Heavy	Unit: Bend or belting butt bend. Finish: Full grain. Water absorption: max 15% in 30 min. Mold resistance: treated as specified. Selections: A—free of defects; B—6% cutting loss; C—12% cutting loss
Straining Gasoline, Orthopedic Devices, etc. Chamois (Sheepskin), Oil Tanned (KK-C-300) Class 1—Pocket Shaped, Sizes A-F Class 2—Natural, Skin Shaped. Sizes: Small, Medium, Large	Unit: Skin. Finish: Flesh split (suede finish, both sides). Area (in min sq in.): Class 1—Size A, 145; B, 220; C, 290; D, 380; E, 460; F, 520. Class 2—Small, 450; medium, 575; large, 675. Water absorption, 4.5 gm water per gm leather per min. Water removal by wringing, 2.5 gm per gm leather per min. Time of wetting: 30 sec max. Removal of water from gasoline: 100% in 60 sec max. Analysis: Iron and aluminum oxides, 1.0% max; free formaldehyde, 0.5% max. Selections: Free of cockle, holes, thin spots or mends. Max scar area: 2 sq in.
Upholstery, Furniture and Auto Cattlehide, Tannage Either Mineral, Vegetable, Synthetic or Combinations (KK-L-291) Type I—Top Grain Type II—Top Grain, Snuffed Type III—Machine Buff Type IV—Deep Buff	Unit: Hide. Finish: a—smooth; b—boarded, hand or machine; c—embossed in fine grain; d—embossed in coarse grain. Area: Types I and II—47 sq ft min; Types III and IV—40 sq ft min. No cracking at 32-deg double-folded bend. No tackiness. Crocking resistance: good. Dye penetration for Types I and II full depth of grain. Selections: A—75% of units defect-free; max defective area of each remaining unit 50 sq in. B—100 sq in. max defective area in each unit

[a]Extracted from *Summary of Specification Requirements for Military Leather*, Headquarters, Quartermaster Research & Engineering Command, U. S. Army, Sept '58.

[b]Single ply.
[c]Double ply.

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MATERIALS AT WORK

...AT A GLANCE

Stainless steel automobile mufflers may provide the best solution to the problem of muffler failure on modern cars. In a 2-year test run, involving more than 30,000 miles of stop-and-go driving, the mufflers, fabricated from type 430 and 302 stainless, showed no sign of corrosion or failure.

Source: Committee of Stainless Steel Producers, AISI; mufflers fabricated by Walker Mfg. Co.

Ceramic tooling is now being used for precision soldering of diodes, rectifiers and electrical connectors. The ceramic boats and inserts are said to be: 1) resistant to wetting by molten solder, 2) capable of withstanding temperatures up to 2000 F, and 3) as hard as tool steel. In addition, ceramic's very low rate of thermal expansion permits extremely close tolerances—the 10 x 10-in. boats or 0.062-in. inserts can be held to tolerances of ± 0.0001 in.

Source: Duramic Products, Inc.

The switch from sand cast aluminum to die cast zinc has resulted in a 75% cost saving in the design of a commutator mounting bracket for a stenciling machine. Although the primary advantage of the change was reduced cost—the zinc part now costs only $1 as compared to $4 for the aluminum part—the change provided several other benefits: machining was reduced from 21 operations to simple trimming; die cast zinc has greater tensile strength than sand cast aluminum; the redesigned part is less bulky and has thinner walls; and it has a smoother surface. Moreover, tolerances are now held to ± 0.002 in. on mounting surfaces and to within ± 0.005 in. for the hole spacing.

Source: American Zinc Institute; part made by A. B. Mueller Co.; used by Defiance Machine and Tool Co.

Glass-reinforced polyester fuel tanks are now being used on heavy diesel transportation trucks. Primary advantage offered by reinforced plastics is a weight saving of up to 190 lb per tank. Other advantages include: corrosion resistance, freedom from maintenance, high resilience and elimination of in-tank condensation. The tanks are available in 40 and 100-gal sizes.

Source: Apex Reinforced Plastics Div., White Sewing Machine Corp.

Tungsten-coated graphite rocket nozzles are now being tested for various rockets and missiles. The graphite nozzles are protected by a coating of up to 1/8-in. thick, high density tungsten applied by the vapor phase deposition process. The process is said to provide high purity, tenacious coatings.

Source: Alloyd Corp.

What may be the first all-aluminum sea water distillation unit is now being developed by the U. S. Army. Presently used de-salting equipment is made from cupro-nickel. The all-aluminum unit is expected to offer these advantages: lighter weight, greater capacity, better fuel economy, and the elimination of large amounts of nickel. Aluminum units now being tested show very little tendency to corrode.

Source: U. S. Army Engineer Research and Development Laboratories.

For more information, turn to Reader Service card, circle No. 362

MATERIALS AT WORK

Graphite Cuts Cost of Centrifugal Casting Dies in Short Runs

Designers of centrifugal casting dies are finding that graphite makes an excellent die material because of its suitability for cut-and-try die designs and for short production runs.

Dies can be altered

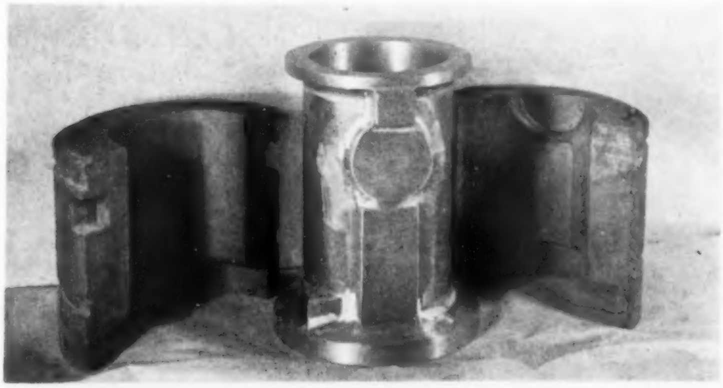
Centrifugal casting dies for long production runs frequently have to be changed in the early stages before the right design is arrived at. Ordinarily, cast iron or steel dies would be prohibitively costly for prototype dies. With graphite, economical changes can be made in the die as its design is perfected and changes are made.

Graphite is also proving valuable for short run centrifugal castings where more costly metal dies cannot be justified by the size of the order. Furthermore, in some complex cases, graphite is simply the only die material that will satisfactorily do the job.

Graphite has good combination of properties

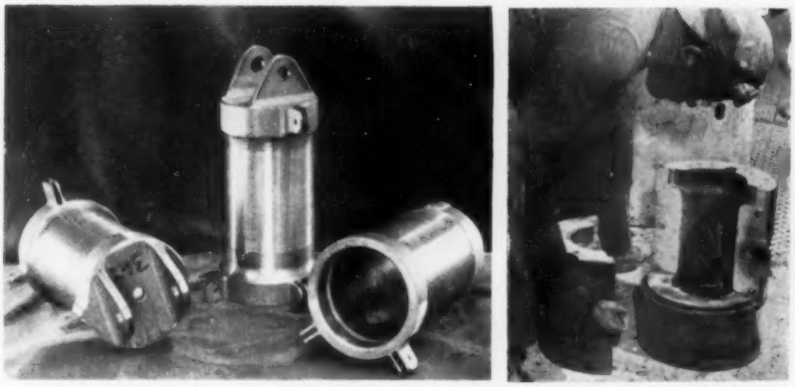
Graphite's suitability as a die material stems from a number of properties. It does not react with most molten metals. Carbon pickup is negligible when casting low carbon stainless steels, and even an extremely "carbon-hungry" metal like titanium has been cast successfully. Graphite's strength actually increases with temperature. Furthermore, due to its high thermal conductivity and low Young's modulus, the material resists thermal shock. It also has a very low thermal expansion and high strength-to-weight ratio.

Excellent chill characteristics are also demanded of a centrifugal die material. Chill effect is roughly the product of mass and specific heat. Since graphite has about twice the specific heat of iron and three times



Aluminum radar antenna component *had to be made by centrifugal casting because it was the only method that would provide necessary strength and density. Despite the part's unusual size and shape, Wisconsin Centrifugal Foundry was able to successfully cast it in a three-piece graphite mold. The mold was designed for prototype production with the stipulation that permanent metal dies would be made when and if the part went into full production. However, when the government approved the radar equipment it specified immediate delivery and there was no time to make metal dies. The graphite development dies were taken from storage and successfully used in meeting the tight production schedule.*

For more information, circle No. 425 ➔



Sway brace for jet bomber *is another example of complicated part requiring a three-piece die. The type 410 stainless steel part (shown in various positions at the left) weighs 14 lb and is made by centrifugal casting because designers found other fabrication methods couldn't compete in quality and economy. Die development was done in graphite (right). After the design was "debugged," permanent dies were made of alloy cast iron.*

1000-lb screw-down nut casting *(left) shown alongside its graphite mold. Mold is about 20 in. long and 24 in. in dia.*

Three other centrifugal castings *shown alongside their graphite molds. Stainless steel bushing (top) is noteworthy because of its odd-shaped flange. Heavy-wall stainless flange bushing (middle) is used in nuclear power plant. Small stainless steel bushing (bottom) goes in hydraulic control system; note complexity of external bosses, flanges and counterbore.*

greater thermal conductivity, it excels in chilling.

Two grades of graphite used

All of the parts shown in the accompanying photographs were made by Wisconsin Centrifugal Foundry, Inc., and its affiliate, Wisconsin Stainless Foundry and Machine Corp. Most of the graphite used by these two companies is a fine-grained CS or ATL grade manufactured by National Carbon Co. These two grades are noted for their good structure and uniform grain size in the various sizes in which they are produced. They have excellent machinability and can be given a very fine finish when required.

More Materials at Work on p 144

MATERIALS AT WORK

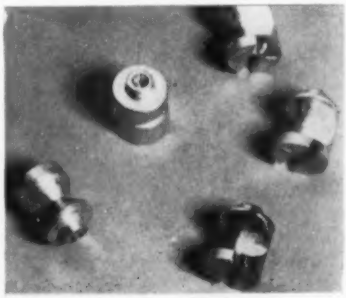
Die Cast Zinc Cam Solves Design Problem

The change from machining to automatic zinc die casting has solved a tricky production problem in the design of an improved electrical terminal board.

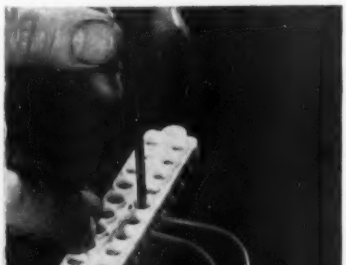
Special cam is key to improvement

The problem involved the production of a tiny V-groove cam—the heart of the connector. According to Willor Mfg. Co., the redesigned connector called for the cam to eliminate all clips, lugs, crimps, plugs, or screw fasteners. The tiny cam (see accompanying photo) had to be less than 11/32 in. in overall length and only ¼ in. in dia. It had to have a screwdriver slot at one end, a small pivot boss at the other end, and a V-groove in the center.

As the cam is turned on its pivot, the groove forms a triangular opening with the wall of the terminal board. One or more bare wire ends can then be inserted between the cam body and cell wall and as the



Specially designed cam is . . .



Gries Reproducer Corp.

. . . heart of terminal connector.

For more information, turn to Reader Service card, circle No. 400

cam is turned the wires are wedged against the wall. Crimping or soldering of lugs or plugs is unnecessary and should tension develop in the wires, the cam automatically rotates further to lock the wires more firmly in place. To disconnect the wires, the cam is simply turned in the other direction.

Machining inefficient

At first, the cams were machined. However, this proved inefficient for three reasons: 1) the small V-groove could not be accurately produced by screw machining because it was not a surface of revolution; 2) tool marks and burrs could not be avoided or satisfactorily removed; and 3) quantity production could not be achieved without excessive rejects.

By turning to an automatic die casting technique, most limitations were eliminated. Now, the cams are mass produced with smooth finishes, proper tolerances and at a cost about 20% less than was previously possible.

Carburetor Air Filter Uses Urethane Foam

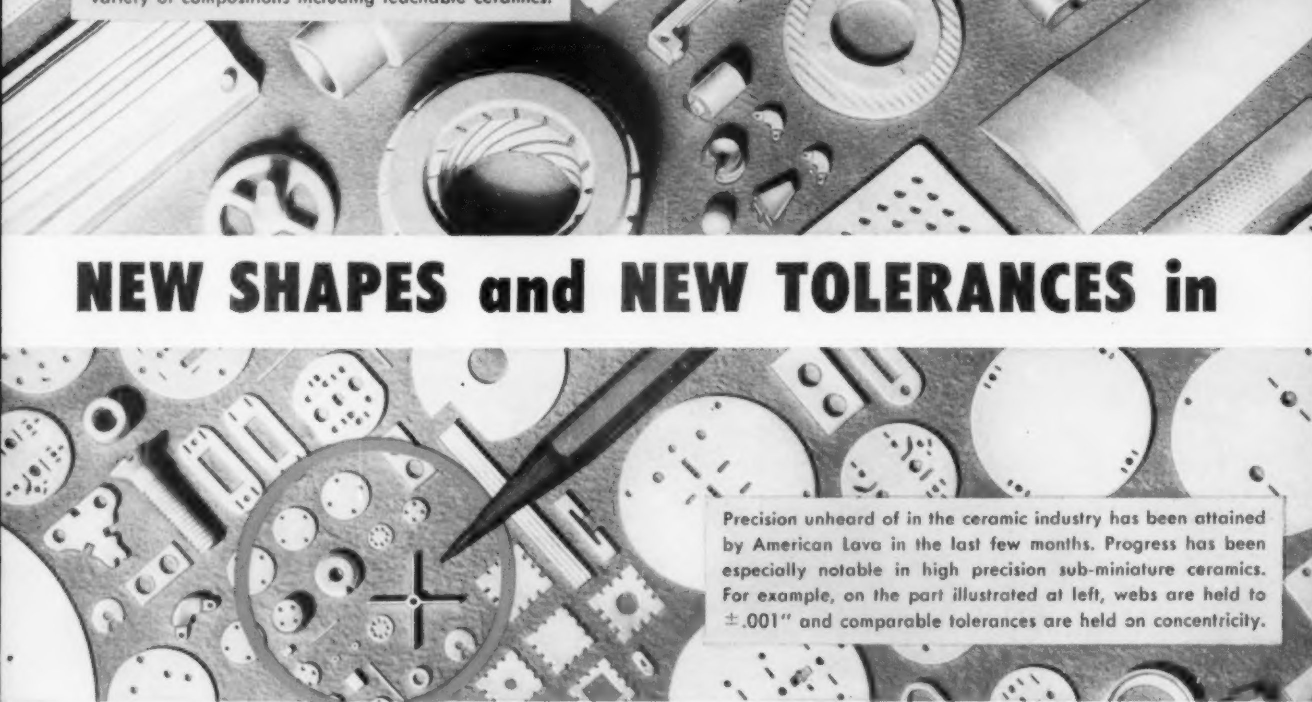
Urethane foam is replacing the metallic mesh and expanded paper-type cartridges normally used in automobile carburetor air filters.

According to Du Pont, many of the new 1960 models have incorporated the cuff-shaped foam filters because they offer the following advantages over previously used filters:

1. They are easily cleaned and replaced.
2. They cost less than resin-treated paper.
3. They are more efficient than metallic mesh filters.
4. Installation labor is less than

Washable, re-usable filter *snaps over metal frame in air cleaner.*

NEW SHAPES and NEW TOLERANCES in



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for either of the two other air filter types; they are elastic and are easily snapped in place (see photo) without the need for gaskets.

5. They are heat resistant and tough.

The foam used is specially processed to give uniform porosity and a completely open pore structure. For increased efficiency, the filter is impregnated with oil.

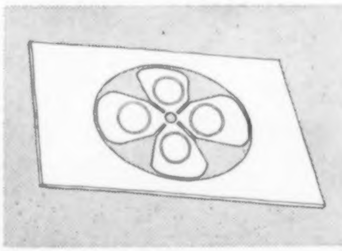
Hole for Fan Used to Make Fan Blade

A clever use has been made of the scrap steel which remained when holes were punched for the placement of fans in the casings of space heaters: the circular pieces of sheet steel are used for the fan blades.

According to Reznor Mfg. Co., fan blades were previously made of aluminum and purchased from outside suppliers. Now the blade is blanked from the casing scrap (20-gage cold rolled steel) in one operation; the hub, a screw machine part, is riveted to the blade; and a special machine sets the proper pitch.

Jones & Laughlin Steel Corp.

***Fan blades** are fabricated from material left over when hole is punched for placement of fan.*



One of the 20-foot continuous-cast Asarcon Ni-Vee gate stems for sluice gates at Lockport, Ill. powerhouse flood control project.

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*NI-VEE is a registered trademark of International Nickel Company.

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For more information, circle No. 322

West Coast Distributor: Kingwell Bros., Ltd., 457 Minna Street, San Francisco, Calif. In Canada: Federated Metals Canada, Ltd., Toronto and Montreal. Distributors in many principal cities.

ENGINEERING & DESIGN

(cont'd from p 118)

Tire Fatigue Failure Not Caused by Cords

Results from the first phase of a continuing research program on cord fatigue in tires has cast considerable doubt on the theory that tire fatigue failure is caused by a gradual loss of cord strength proportional to tire mileage.

In a report on the first phase of the study, W. G. Klein, M. M. Platt and W. J. Hamburger of Fabric Research Laboratories, Inc., Dedham, Mass., noted that the original objectives of their research program were to define the mechanism of cord fatigue and then seek ways to improve resistance to fatigue. However, in studying the cords it was discovered that "what has been referred to as fatigue failure is almost certainly not caused by fatigue of the cords or their components. In fact, fatigue, defined as a continuous loss in cord strength, was found not to exist in significant proportions."

The report was read at a recent meeting of the Technical Assn. of the Pulp and Paper Industry (TAPPI).

Major emphasis on tires made of viscose cord

The researchers dissected and quantitatively and qualitatively examined 500 tires run on a New York City taxi fleet at rated pressures and loads up to 100,000 miles of use. Major emphasis was on tires constructed of Tyrex viscose cord, but corresponding studies were made on a smaller group of nylon cord tires.

Here's what Klein and his associates found:

1. In tires which had not failed (only four failed) the pattern of cord strength vs. mileage was similar in both nylon and viscose tires. A fairly rapid drop in strength of flex zone cords occurred in the first 20,000 miles, a very gradual loss between 20,000 and 60,000 miles, and a slightly more marked loss from 60,000 to 100,000 miles. The loss in strength in both the viscose and nylon tires was not sufficient to cause failure in up to 100,000 miles of use.

2. The four tires rated as fatigue failures were dissected and the strength of the cords tested both

near and away from the point of failure. The cords had a strength comparable to what could be expected if the tire had not failed.

3. Individual viscose and nylon filaments were examined and the conclusion drawn that weakening of filaments was so insignificant that it played no role in fatigue of the cords.

What does cause failure?

If so-called fatigue failures are not caused by lowered cord strength, what does cause them? An answer awaits further research, according to Klein. He did note, however, that a breakdown in adhesion of the cord to the rubber may be the cause. Once adhesion gives way the cords are left to flex unrestrained and may very quickly fail whether tires have been used one mile or 100,000 miles.

Radiation Shields for Space Vehicles

A major problem in designing a manned space vehicle is providing a lightweight radiation shield, says Norris F. Dow of General Electric Co.'s Missile & Space Vehicle Dept., 3198 Chestnut St., Philadelphia 1.

At present, lead is the most practical type of shielding since it stops both protons and gamma rays. However, a minimum of 100 lb per sq ft of lead is needed to protect a man from natural radiations in space.

Dow told those attending a recent Manned Space Station symposium in Los Angeles that a man at 2200 miles altitude without shielding would receive his permissible weekly radiation dose in slightly more than a minute.

Other shielding methods

Dow outlined the problems in developing other methods of radiation shielding that "conceivably offer hope of reducing shield weight."

Active shielding—One is an active shielding consisting of two concentric spheres. The inner sphere is given a positive electrostatic charge creating an electrical belt that stops any harmful protons that contain less energy than the protective belt itself.

The obstacle to this kind of shielding, Dow says, is that heavy ground

For more information, turn to Reader Service card, circle No. 376

based electrostatic equipment has not been able to produce anything near the required voltages.

Passive shielding—Another method is a passive shielding using hydrogen atoms which can stop protons "approximately five times as effectively as lead, on a weight basis."

However, a heavy composite material probably would have to be used to protect against high energy gamma rays that are produced when the proton rays are stopped by the hydrogen atoms. The weight of this shield, Dow says, would tend to cancel out the advantages of using light weight hydrogen atoms to stop the protons.

Coating Helps in Cold Extrusion of Titanium

Titanium metal coated with a fluoride-phosphate coating and lubricated with a solid film lubricant has successfully been cold extruded into wire and tubing by A. M. Sabroff and P. D. Frost, of Battelle Memorial Institute's Light Metals Div., 505 King Ave., Columbus 1, Ohio.

Though cold extrusion is widely used in the forming of steel and certain other metals, the process has been applied little, if at all, in the production of titanium products, according to Sabroff and Frost. They say fabrication of titanium by cold extrusion has probably been retarded most by the inability to achieve a satisfactory surface finish on the metal.

The new coating imparts a good surface finish to the metal and acts as a lubricant retainer. It is applied by immersing titanium in a fluoride-phosphate bath operated at room temperature. The solid film lubricant used in the extrusion technique is a self-drying, gum-resin mixture containing graphite and molybdenum disulfide.

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TECHNICAL LITERATURE

(cont'd from p 51)

Books

Polyester Resins. *J. R. Lawrence. Reinhold Publishing Corp., New York. 1960. Cloth, 5 by 7 in., 260 pp. Price $5.75*

This book covers all aspects of the unsaturated polyester resin industry from historic background, chemistry, curing mechanisms and manufacturing to techniques used in processing the resins for use in reinforced plastics, casting and coating applications. Particular emphasis is given to formulating resins for special properties such as weathering and flame resistance. A chapter on coating applications is said to be the most complete coverage ever published on this relatively new use for polyester resins.

ASTM Standards on Materials. *American Society for Testing Materials, Philadelphia.*

Standards on Copper and Copper Alloys: B-5. *1960. Cloth, 6 by 9 in., 780 pp. Price $7.50*

Covers methods of test, definitions, specifications, classifications, and recommended practices applicable to copper and copper alloys, filler material, pipe, tubes, wire, rod, bar, shapes, die forgings, plate, sheet, strip, rolled bar, ingots and castings.

Standards on Metallic Coated Iron and Steel Products: A-5. *1960. Cloth, 6 by 9 in., 176 pp. Price $3.50*

Covers zinc-coated wire, strands, sheets, pipe and fencing. Also aluminum-coated wire, aluminum-coated iron and steel parts, and terne-coated sheets.

The Electrolytic and Chemical Polishing of Metals in Research and Industry: 2nd Edition. *W. J. McG. Tegart. Pergamon Press Inc., New York. 1960. Cloth, 5½ by 8½ in., 149 pp. Price $6.50*

Although emphasis of the book is primarily on research, three chapters deal specifically with industrial applications of electrolytic and chemical polishing methods. Apparatus, techniques, precautions required, and limitations of the processes are discussed in relation to such topics as electropolishing in molten electrolytes, and electrolytic and chemical polishing of some of the rarer metals and their alloys.

Encyclopedia of American Associations: Geographic Index—2nd Edition. *Gale Research Co., 1116 Book Tower, Detroit. 1959. Paper, 9½ by 11½ in., 172 pp. Price $15*

Lists by state and city 8892 national associations, professional societies and other nonprofit organizations.

Electropolishing, Anodizing and Electrolytic Pickling of Metals. *N. P. Fedot'ev and S. Ya. Grilikhes. Translated from the Russian by A. Behr. Robert Draper Ltd., Teddington, Middlesex, England. 1959. Cloth, 5½ by 8½, 300 pp. Price $8.40*

Gives an insight into the present state of Russian technical knowledge and industrial experience in electropolishing, anodizing and electrolytic pickling. Particularly enlightening is the section on electropolishing of steels in which the Russians appear to have

reached a more advanced stage of development and much wider industrial application than Western countries.

Welding Handbook: 4th Edition—Section 3. *Edited by A. L. Phillips. American Welding Society, New York. 1959. Cloth. 6 by 9 in., 512 pp. Price $9*

Contains chapters on the following subjects: forge, thermit and induction welding; surfacing; metallizing; brazing; soldering; welding of plastics; adhesive bonding of metals; arc cutting; welding by cold working; and ultrasonic and stud welding.

Reports

Research costs SCIENCE AND ENGINEERING IN AMERICAN INDUSTRY: REPORT ON A 1956 SURVEY. *National Science Foundation. 1959. 122 pp. Available from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Price 70¢*

Discusses research and development costs and personnel in 1) manufacturing and other industries, 2) commercial laboratories and engineering service firms, and 3) trade associations.

Photomicrography of metals PHOTOMICROGRAPHY OF METALS. *46 pp. 1959. Eastman Kodak Co., Rochester, N. Y. Price 50¢*

Information on the metallographic microscope, illumination, filters in metallography, photographic materials, exposure determination, and processing and printing.

Nuclear fuel elements PHYSICAL AND ENGINEERING PROPERTIES OF MATERIALS FOR NUCLEAR FUEL ELEMENTS. *H. H. Hausner. Sylvania-Corning Nuclear Corp., Bayside, N. Y. 55 pp. Price $1*

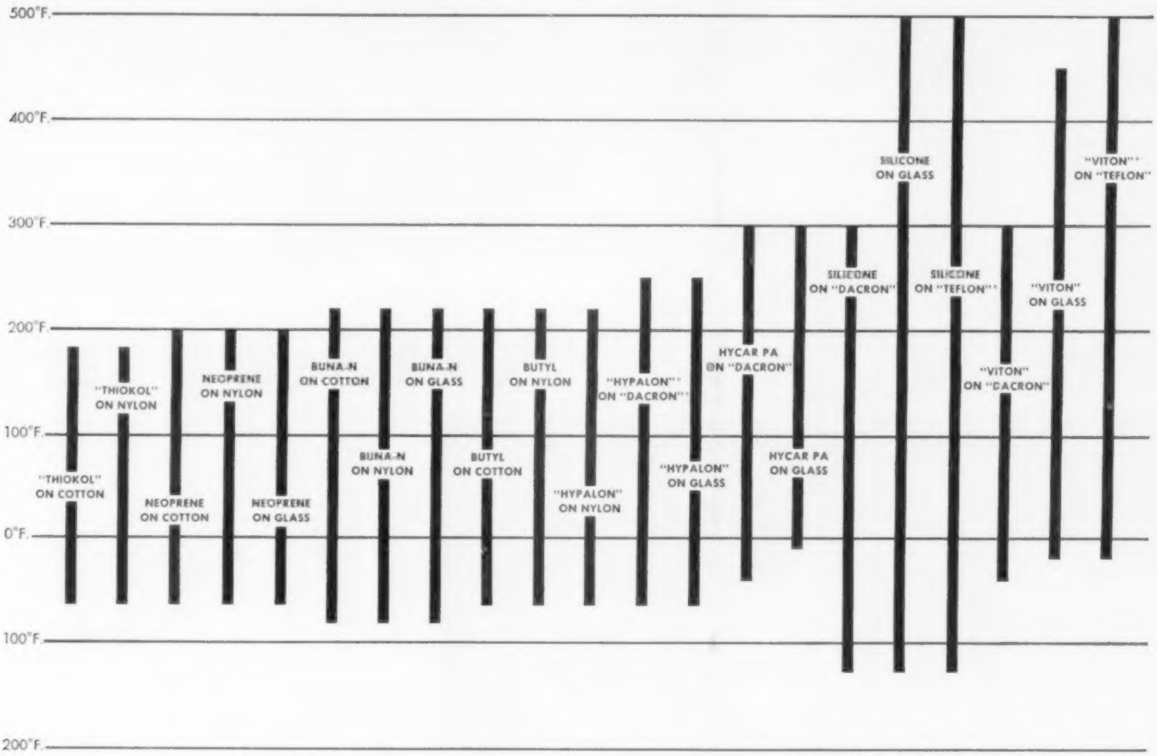
Physical and thermal properties of uranium, thorium, plutonium, ceramics, zirconium and Zircaloy-2, aluminum, stainless steel, graphite, and other high temperature materials.

Materials testing INVESTIGATION OF THE HIGH INTENSITY ARC TECHNIQUE FOR MATERIALS TESTING. *C. Sheer, C. D. Fitz and others, Vitro Laboratories. Nov '58. 109 pp. Available from Office of Technical Services, Dept. of Commerce, Washington 25, D. C. Price $2.50 (PB 161265)*

Protecting molybdenum COATINGS FOR PROTECTING MOLYBDENUM FROM OXIDATION AT ELEVATED TEMPERATURES. *E. S. Bartlett, H. R. Ogden and R. I. Jaffee. Defense Metals Information Center, Battelle Memorial Inst., 505 King Ave., Columbus 1, Ohio (Rpt. No. 109)*

Discusses the results of a number of tests performed on coated molybdenum parts. These include investigations of coated molybdenum for potential use as jet engine turbine buckets, nozzle vanes, thermocouple protection tubes, and ramjet flameholder gutters.

Properties of wood IMPORTANT TECHNICAL PROPERTIES OF WOODS. *O. Graf. 1959. 8 pp. Available from SLA Translation Center, John Crerar Library, 86 E. Randolph St., Chicago 1. Price $1.80 (No. 59-20463)*



Upper serviceable limit is the highest temperature at which the material can be folded 180° back upon itself without cracking after 72 hours' exposure. Low limit is the lowest temperature at which the material can be bent around a 1" mandrel after 1 hour's exposure.

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For more information, turn to Reader Service card, circle No. 359

What's new IN MATERIALS

(cont'd from p 12)

New Polypropylene Resin Sold in Three Process Grades

A new polypropylene resin, now in commercial production (see M/DE, June '60, p 19), is said to be the first such polypropylene sold in three processing grades—1.5, 3.5 and 5.5 melt indexes measured at 450 F. The resin, called Escon, is available from Enjay Co., Inc., 15 W. 51st St., New York 19.

According to J. E. Wood, III,

PROPERTIES OF ESCON POLYPROPLYENE

PHYSICAL PROPERTIES	
Melt Index, gm/10 min	1.5, 3.5, 5.5
Density, gm/cu cm	0.902
Burning Rate	Slow
Mold Shrinkage, in./in.	0.015-0.030
Melting Point, F	335
Vicat Softening Point (1 kg), F	280
Coef of Ther Cond, Btu/in./sq ft/hr/°F	1.13
Coef of Ther Exp, per °F	0.00011
Specific Heat, Btu/lb/°F	0.46
MECHANICAL PROPERTIES	
Yield Strength (2 in./min), psi	4700
Elongation (2 in./min), %	15
Impact Strength (Izod), ft-lb/in.	
Notched	1
Unnotched	16
Hardness (Rockwell)	R85
Elastic Modulus (2 in./min), psi	150,000
Compr Yld Stress (0.05 in./min), psi	6000
Stiffness in Flexure, psi	180,000
Taber Abrasion Resistance*, mg loss/1000 cycles	28
ELECTRICAL PROPERTIES	
Dielectric Strength, v/mil	
Short Time	660
Step-by-Step	650
Dielectric Constant (10^6 cps)	2.1
Dissipation Factor (10^6 cps)	0.00025
Volume Resistivity, ohm-cm	1×10^{15}
ENVIRONMENTAL PROPERTIES	
Water Absorption, %	0.010
Environmental Stress Cracking	None
CHEMICAL RESISTANCE	
Weak Acids	Excellent
Strong Acids	Good
Weak Alkalis	Excellent
Strong Alkalis	Excellent
Organic Solvents	Good below 175 F

*CS-17 wheel (1000-gm load).

Extruded polypropylene *is chopped into small pellets for packaging.*

Enjay president, Escon's three levels of processability are being provided without sacrificing strength and resistance to heat distortion. Properties of all three grades are the same.

The 1.5 melt index resin has low flow and low flash for high speed operations at high pressures and temperatures. It can be used to make small, precision molded parts. The 3.5 grade has intermediate flow and excellent processability for most high speed molding operations at conventional pressures and temperatures. The 5.5 grade has high flow for rapid filling of intricate molds under high speed conditions.

According to Enjay, the new material is the first polypropylene resin made by a continuous process. The process (details not revealed) is said to insure uniformity in the end product. **KEY NO. 604**

Rubber-Base Paste

A general purpose rubber-base repair material can be used for sealing or calking around machinery, insulating electrical equipment, making gaskets, and as a coating for protecting piping and machinery

against corrosive liquids. It can also be used for repairing conveyor belting.

The new material is supplied in paste form by Devcon Corp., Danvers, Mass. It is said to be unaffected by oil, gasoline and most chemicals. The paste bonds well to rubber, iron, steel, aluminum, bronze, ceramics, wood and plastics.

KEY NO. 605

Extruded Steel Shapes Made by New Process

A faster, more economical process for extruding carbon and stainless steel shapes has been developed by H. M. Harper Co., Metals Div., Morton Grove, Ill. In the technique, small ingots measuring 5½ to 7½ in. are processed directly by extrusion from the cast material into the finished shape without rolling.

H. M. Harper, president, says the new process produces a finished product with as much tensile strength, or more, than steel products made by the conventional hot rolling method.

KEY NO. 606

Semiconductor for Thermoelectric Cooling

Development of a new semiconductor alloy for thermoelectric cooling has been announced by General Thermoelectric Corp., P. O. Box 253, Princeton, N. J. A big feature of the new material is its higher thermoelectric cooling efficiency compared to other available thermoelectric materials.

First quaternary alloy

Known as Neelium, the semiconductor material is said to be the first quaternary alloy marketed for thermoelectric applications. To date, only binary and ternary alloys have been commercially available.

The alloy consists of bismuth, tellurium, selenium and antimony. It is fabricated into thermocouples which are then assembled into a device known as a Frigistor (see accompanying photo).

Potential applications

Typical applications for Frigis-

Thermoelectric device *(right) consisting of eight thermocouples is compared in size with a typical germanium transistor.*

tors include their use in devices that pump heat away from high power transistors. The heat pumping capacity for a Frigistor containing eight Neelium thermocouples is reported to be two to three times greater than that of similar devices of much larger size.

Additional thermoelectric applications for Frigistors include cooled microscope and microtome tables, vacuum cold traps, dew-point hygrometers, reference junctions for calibrating thermocouples, photomultiplier cathode coolers, and water distillation apparatus. **KEY NO. 607**

Resin-Treated Fabrics for Electrical Uses

A new line of B-stage polyester-treated fabrics and tapes has been developed for use as intermediates in rolling insulating tubes, and in forming or molding shapes or contours for mechanical and electrical equipment.

The treated fabrics and tapes are available from Westinghouse Electric Corp., Micarta Div., Trafford, Pa. They are made of a variety of base materials, including glass and synthetic fabrics, asbestos, and asbestos-glass mat.

Fully catalyzed, they can be stored at room temperature for at least six months without deterioration, according to Westinghouse. The treated fabrics are said to be as easily handled as standard glass-base fabrics.

(continued on p 168)

DOW NEWS ABOUT PRODUCT DESIGN AND MATERIALS

From the technical development laboratories at Dow comes a steady stream of new applications for those versatile materials—the thermoplastics . . . new applications that accent beauty, function, production economy . . . new applications that stimulate ideas for your own designs and processes. The products described on these pages contain just a few of the Dow thermoplastics that are serving today's designers . . .

FUNCTIONAL DOW PLASTICS EXTEND PRODUCT DESIGN LIMITS

Within each broad category of Dow thermoplastics there are often several different formulations designed to pinpoint the functional requirements of designers and processors. Thus, you can select an individual Dow plastic material to extend the limits of your requirements for moldability, durability . . . lightness, inertness . . . beauty, clarity, or color . . .

One Dow thermoplastic—Tyril®—adds an extra measure of beauty, moldability and physical strength to the design of this modern built-in blender. Mixing, chopping, or liquefying in a matter of seconds, are just a few of its accomplishments.

To ensure its top performance under all forms of kitchen punishment, the designer specified clear Tyril for molding the blending jar. Tyril—a Dow copolymer of styrene and acrylonitrile—gives this appliance part toughness and high shock resistance to withstand the churning action of the high-rpm knife blades . . . its chemical resistance helps the jar stand up under the attacks of food acids and cooking ingredients . . . its temperature resistance protects against cracking or crazing over a wide temperature range—from mixing boiling liquids to crushing ice . . . and excellent moldability enables Tyril to reproduce the jar's complex shape and the finely detailed cup and ounce measuring marks. Washing presents no hazards, either. Detergents won't harm Tyril, nor will hot water, and it withstands normal abuse.

One of the problems designers have had to face when insulating a product is compensating for the added bulk and weight of thermal insulation. Today, designers have solved this problem with Pelaspan® — Dow expandable polystyrene in bead or pellet form. Foamed in place by the manufacturer, Pelaspan provides thermal insulation with negligible bulk or weight for this beverage cooler. (opposite page).

Pelaspan beads can be pre-foamed, expanded many times. When a molding or structural cavity is filled with them, and the beads are further expanded by steam, they tightly close up the interstices and make a molding of uniform density. The closed-cell structure created

For more information, turn to Reader Service card, circle No. 450

What's new IN MATERIALS

Polyester-treated fabrics—Grades TT-9451 and M-41524-BV B-stage polyester-treated glass fabrics are recommended for formulating rigid laminates having good moisture resistance and stable physical properties at elevated temperatures.

The treated fabrics are said to bond well to many materials at relatively low temperatures. They can also be used as laminating intermediates for the fabrication of barrier tubes, angles, channels and other shapes.

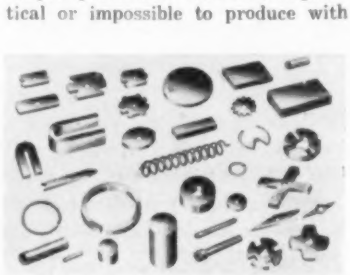
Another B-stage polyester-treated glass fabric, called Grade TT-9453, is recommended for barrier tube rolling and general low pressure banding applications. **KEY NO. 608**

Epoxy-treated fabrics—Grade M-4142-FA is an epoxy-treated asbestos-glass fiber mat intermediate for insulating field coils requiring Class B (265 F) performance. Its base is asbestos paper reinforced with glass fibers. **KEY NO. 609**

Improved Magnetic Alloy Is Easy to Machine

An improved copper-nickel-iron permanent magnet alloy has been introduced by Hoskins Mfg. Co., 4445 Lawton Ave., Detroit 8. Chief advantage of the alloy is its high coercive force and energy product values combined with excellent ductility and machinability. The developer does not say how ductility is imparted to the material.

According to the producer, the alloy can be stamped, machined and formed by conventional methods into a variety of complex, intricately shaped parts that would be impractical or impossible to produce with



Typical parts *that can be made from improved permanent magnet alloy.*

For more information, turn to Reader Service card, circle No. 381

hard, brittle types of cast or sintered permanent magnet materials.

Potential applications

Field tests show that timer motors for appliances, speedometers, aircraft instruments, electronic equipment and control systems are some of the products in which the alloy can be used advantageously.

The new material is supplied as finished magnets, and as wire and strip in a range of sizes and shapes.

KEY NO. 610

Two Circuit Boards, Conductive Coating

Two new printed circuit boards and an electrically conductive resin coating containing copper for printed circuits have been introduced.

Epoxy circuit boards

Plastronic Engineering Co., 721 Boston Post Rd., Marlborough, Mass., is marketing a miniature circuit board made of epoxy. The board is said to have good heat and chemical resistance, high dielectric characteristics, low moisture absorption, good mechanical strength, and good dimensional stability.

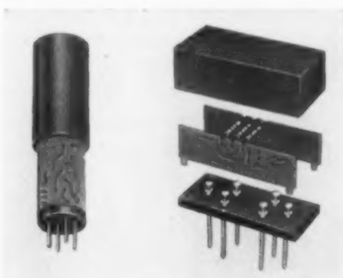
The circuits are high conductivity silver, but gold-plated circuitry can be supplied for added tarnish and corrosion protection.

The producer says the circuit boards can be supplied flat, oval, concave and convex. Standard thickness of the printed circuit board is 0.050 in.

KEY NO. 611

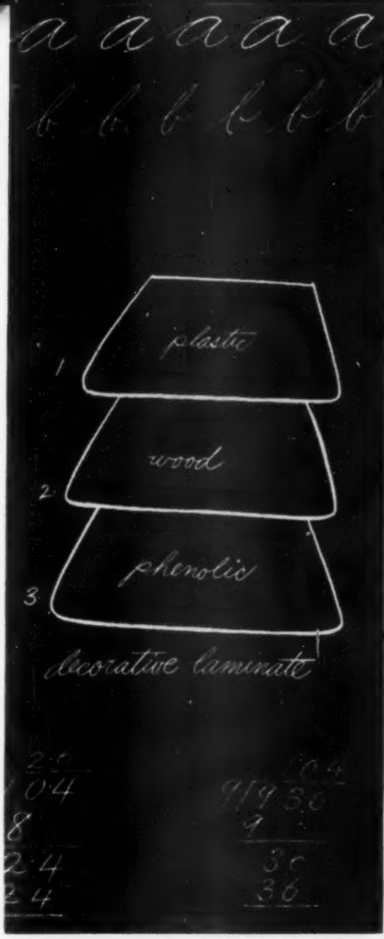
Polyolefin circuit boards

Printed circuit boards made from irradiated polyolefins laminated to fiberglass cloth are available from



Epoxy circuit boards *can be made in flat, concave and convex shapes.*

Product-Design
BRIEFS
from Durez



DECAR PLASTIC CORPORATION

MIND OVER MOTOR

This phenolic fan will help an electric motor run cool and quiet for years to come.

It won't warp out of shape if the motor toils for hours in the hot sun or sits idle for days in a damp cellar. It won't rattle or hum.

To the men who make the motor, it means a better product; the right blade contour with no machining. Precise concentricity and balance, molded in. Light weight.

Perhaps you could use these advantages of Durez phenolic in one of your products. Your custom molder will be glad to talk with you about it.

THE BROWN-BROCKMEYER CO.

LESSON IN LAMINATES

Think back—to a classroom of desks with varnished ink-stained tops gouged with the initials of your predecessors.

Then think ahead, as the makers of school furniture are doing. They use tough plastic Decarlite desk-top sandwiches—laminates that take pupil punishment in stride. The best of these have a layer of Durez phenolic in them.

Lesson for today: if you want a laminate to be stiffer and harder, to be dimensionally stable, to last longer and hold its shape better, think of Durez phenolic resins. They're low in cost. They bond, impregnate, harden—and stay that way for keeps. If you'd like to know more about what these versatile resins can do for you, write us describing the problem.

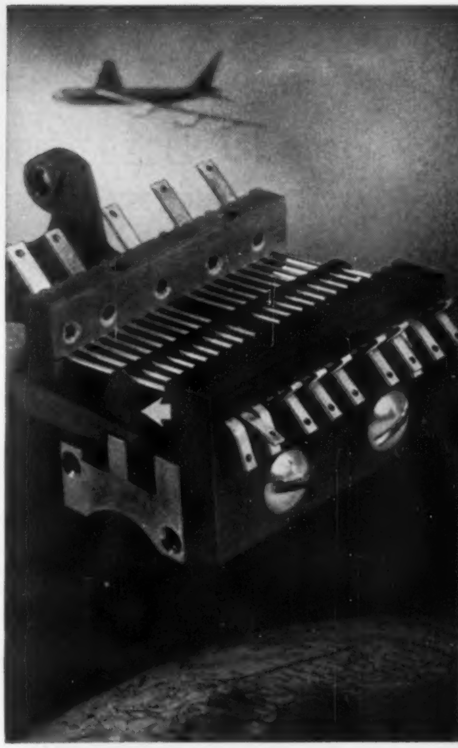
BRAIN FOR A BOMBER

This is a read unit of a latitude data computer, part of the B-52's intricate bombing-navigation system made by IBM.

Engineers had trouble molding one part (arrow). They were using a plastic which required a high molding pressure. This high pressure damaged the steel part of the pin assembly by forcing it into the locating portion of the mold.

A switch to a Durez diallyl phthalate molding compound was the answer. This material molds at lower pressures and provides the right physicals with virtual freedom from cold flow and creep.

When you want reliability in a system—with no room for compromise—a Durez diallyl phthalate compound may be your solution, too. For data on these premium-quality materials, write us or check the coupon.



IBM FEDERAL SYSTEMS DIVISION

For more information on Durez materials mentioned, check here:

☐ Phenolic molding compounds—descriptive Bulletin D400
☐ Phenolic resins—illustrated bulletin describing uses
☐ Diallyl phthalate molding compounds—data sheets

Clip and mail to us with your name, title, company address.
(When requesting samples, please use business letterhead.)

DUREZ PLASTICS DIVISION

1407 WALCK ROAD, NORTH TONAWANDA, N. Y.

HOOKER CHEMICAL CORPORATION

HOOKER CHEMICALS PLASTICS

For more information, circle No. 393

Enflo Corp., Fellowship Rd. and Rte. 73, Maple Shade, N. J.

The boards, called Enrad II, are said to have good heat, moisture and dielectric strength characteristics for VHF and UHF applications. When laminated to copper, the boards are said to withstand a 20-sec solder dip test, as well as a 5 to 9-lb peel-back test.

The producer says the boards can be made as thin as 0.010 in. They can be bent to fit tight spaces without cracking or crazing. **KEY NO. 612**

Conductive coating

Etchomatic, Inc., 182 Newton St., Waltham, Mass. is marketing an electrically conductive resin coating containing copper for printed circuits. The coating, called Conduct-a-Coat, is applied by dipping, removing excess, oven drying, light sanding, and copper strike. This method is said to fill and level irregularities, and contributes to a smooth, precision plated hole.

The coating method does not require expensive equipment or laboratory controls. **KEY NO. 613**

Six New Processes for Finishing Metals

Allied Research Products, Inc., 4004 E. Monument St., Baltimore 5, Md. has added six new products to its line of metal finishing processes.

Three of the processes are chromate conversion coatings for nonferrous metals, two are brightening addition agents for zinc plating baths, and one is an addition agent for copper plating solutions.

Chromate coatings—The chromate conversion coatings are designated Iridite Nos. 1P, 7P and 11P. All are supplied in powder form.

Iridite No. 1P produces a dark green, olive drab film on zinc plate and a brown film on cadmium plate;

Correction

Spaulding Fibre Co.'s new gasket material is known as No. 44—not No. 88 as inadvertently given in the May issue, p 222, line 7. Also, the latex binder is NBR, not SBR.

News about COATINGS FOR METALS

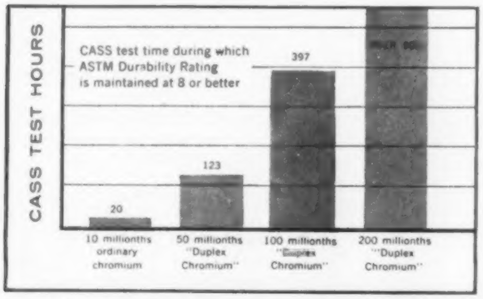
from Metal & Thermit Corporation

The thicker the "Duplex Chromium" ...the longer the plating lasts

The thicker this new, combination decorative chromium plate, the longer the finish lasts. This, in brief, is what accelerated corrosion tests show repeatedly. Increased corrosion resistance always results from thicker deposits of M&T "DUPLEX CHROMIUM" over a suitable nickel undercoat—whether tests are conducted by the CASS (1) or Corrodkote (2) methods.

This pattern of protection is consistent whether panels are steel, or zinc die castings. Note in the graph how the durability of the chromium plate is upgraded by thicker deposits. A thickness of 50 millionths of an inch of M&T "DUPLEX CHROMIUM" delivers a dramatic increase in durability. And a 100 millionths thickness enables samples to survive 100 CASS test hours and still maintain an ASTM durability rating at near the perfect level of 10. This achievement becomes all the more amazing when it is realized that automotive specifications till now only called for decorative chromium plate able to endure 16 hours of CASS.

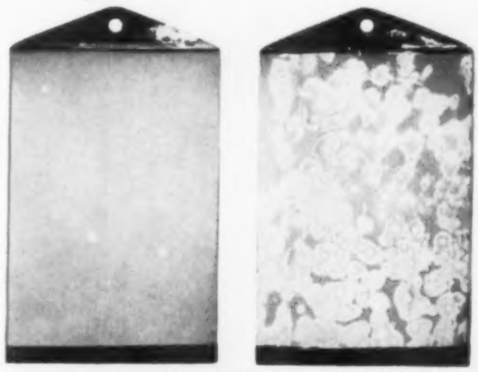
Specifying the additional chromium thickness is a way to increase the outdoor life of the bright finish. And for the ultimate in performance, M&T "DUPLEX CHROMIUM" now brings within reach of designers a decorative chromium plate that also helps solve production problems.



Graph indicates how corrosion resistance of chromium plate and ability to maintain ASTM durability rating of 8 or better in CASS testing increases with thickness. All test panels had 0.75 mil copper and 0.75 mil nickel undercoats—only the chromium was varied.

A UNIQUE DOUBLE PLATE

M&T "DUPLEX CHROMIUM" consists of a deposit from the Unichrome Crack-Free Chromium bath, topped by a deposit from another special Unichrome SRHS® Chromium bath. The former blocks penetration of corrosives to the undercoats; the latter minimizes the effects of localized corrosion cells resulting from irregularities in the surface of the basis metal.



Left: zinc die cast panels with 0.10 mil "Duplex Chromium" over copper and nickel undercoat, when subjected to 6 cycles of Corrodkote test, still rated 9.

Right: zinc die cast panel with 0.01 mil ordinary chromium over identical undercoats as panel to left rated only 1 after same 6 cycles.

Both of these Unichrome SRHS® (self regulating high speed) baths are ideal for plating thicker chromium. They not only speed production but also simplify it. They give more uniform plate distribution and covering power, so that recesses, too, receive adequately thick deposits.

More data on tests and technology available. Send for your copy.

(1.) Copper-accelerated acetic acid salt spray.

(2.) Standard, uniform highly corrosive slurry applied on test piece, which is then placed in non-condensing humidity cabinet. Each cycle is 16 hours.

coatings and finishes

METAL & THERMIT CORPORATION
General Offices: Rahway, New Jersey

For more information, turn to Reader Service card, circle No. 428

Iridite No. 7P produces a protective and decorative finish on copper alloys; and Iridite No. 11P produces a clear, bright protective and decorative film on zinc-plated surfaces. The film can be dyed to provide many pastel shades. **KEY NO. 614**

Zinc brighteners—The two new brightening agents for zinc plating baths are called Isobrite No. 333 and No. 334. They are designed for high current density plating in cyanide zinc solutions. The developer says their formulations and results are identical, the major difference being that Isobrite No. 333 contains more brightener per gallon than Isobrite No. 334. **KEY NO. 615**

Copper brightener—Isobrite No. 625 is a liquid organic addition agent designed for copper plating solutions. It is said to provide a smooth, ductile copper deposit. The formulation can be used in a variety of installations ranging from small barrels to large buffing operations. **KEY NO. 616**

Asbestos Prepreg Withstands 5000 F

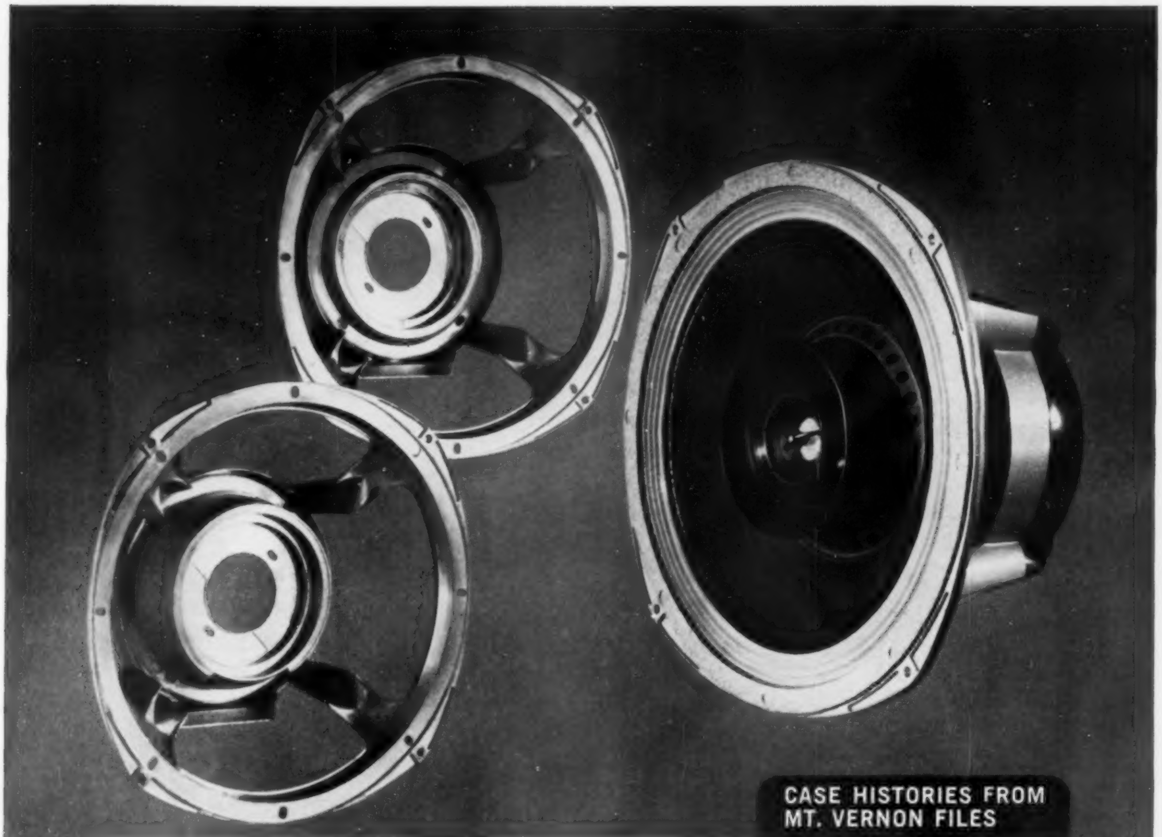
A new prepreg composed of nonwoven asbestos felt impregnated with a phenolic resin and an inorganic filler is available from Johns-Manville, 22 E. 40th St., New York 16.

The material, called Thermomat, is designed for high temperature service in rockets and missiles. In a typical missile application, a ⅛-in. thick sheet of the cured material

PROPERTIES OF THERMOMAT*

PHYSICAL PROPERTIES	
Density, lb/cu ft	106
Coef of Ther Exp (70-400 F), per °F	5.51×10^{-6}
Ther Cond, Btu/hr/sq ft/°F/in.	2.5
MECHANICAL PROPERTIES	
Tensile Strength, psi	15,500
Mod of Elast in Tension, psi	2.14×10^6
Mod of Rupture, psi	25,300
Shear Strength, psi	20,300
Compressive Strength, psi	
Edgewise	24,500
Flatwise	50,300
Rockwell Hardness	K74

*Cured 15 min at 300 F followed by a post-cure of 24 hr at 300 F, then 66 hr at 350 F.



For more information, turn to Reader Service card, circle No. 420

What's new IN MATERIALS

protected the metal casing of a solid fuel compression chamber operating at 5000 F for approximately 90 sec.

The prepreg is supplied as a sheet measuring 14 in. wide by 12 ft long by 3/16 in. thick. The producer says the sheet is extremely conformable, and permits convenient one-man layups.

The prepreg is supplied in a variety of styles with varying resin, asbestos and filler contents.

KEY NO. 617

Coal Tar Coatings Resist Chemicals

Two cold applied, coal tar emulsion type coatings are being marketed by Koppers Co., Inc., Koppers Bldg., Pittsburgh 19. Both coatings are said to be highly resistant to chemicals.

▶ One is a heavy duty coating suited for intermittent splash and high chemical "fallout" areas. The coating, called Bituplastic No. 33, is intended for use on structural steel, deck areas and sheet piling. It is said to withstand temperatures up to 400 F, and to have good abrasion resistance. The coating can be applied by brush, roller or spray. **KEY NO. 648**

▶ The other coating, called Bituplastic No. 44, has been successfully used to adhere cellular glass insulating blocks to storage tanks and to underground piping, and as a general purpose insulation mortar. It is said to be ideal as a top coating for insulation. **KEY NO. 649**

Polysulfide Compound Seals at –70 to 300 F

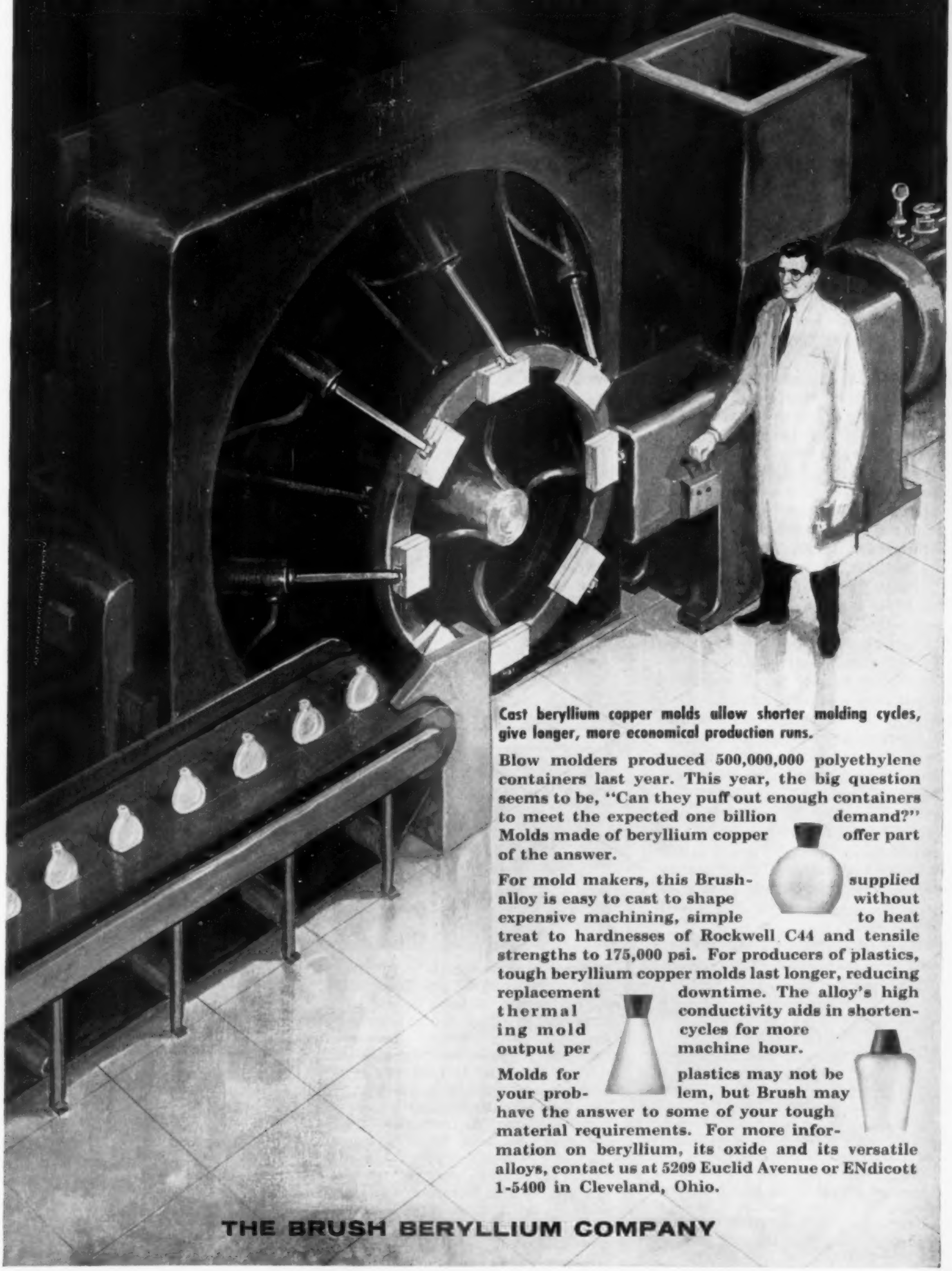
A polysulfide sealing and potting compound for use at temperatures from –70 to 300 F has been intro-

ELECTRICAL PROPERTIES OF PR-1460*

Volume Resistivity, ohm-cm	2.0×10^{11}
Surface Resistivity, ohm-cm	3.5×10^{11}
Dielectric Strength, v/mil	250
Dielectric Constant (1 mc)	7.3
Power Factor (1 mc)	0.03

*Specimens cured 48 hr at 77 F.

BERYLLIUM COPPER HELPS BLOW MOLDERS FILL HUGE DEMAND



Cast beryllium copper molds allow shorter molding cycles, give longer, more economical production runs.

Blow molders produced 500,000,000 polyethylene containers last year. This year, the big question seems to be, "Can they puff out enough containers to meet the expected one billion demand?" Molds made of beryllium copper offer part of the answer.

For mold makers, this Brush-supplied alloy is easy to cast to shape without expensive machining, simple to heat treat to hardnesses of Rockwell C44 and tensile strengths to 175,000 psi. For producers of plastics, tough beryllium copper molds last longer, reducing replacement downtime. The alloy's high thermal conductivity aids in shortening mold cycles for more output per machine hour.

Molds for plastics may not be your problem, but Brush may have the answer to some of your tough material requirements. For more information on beryllium, its oxide and its versatile alloys, contact us at 5209 Euclid Avenue or ENdicott 1-5400 in Cleveland, Ohio.

THE BRUSH BERYLLIUM COMPANY

For more information, turn to Reader Service card, circle No. 414

duced by Products Research Co., 3126 Los Feliz Blvd., Los Angeles 39.

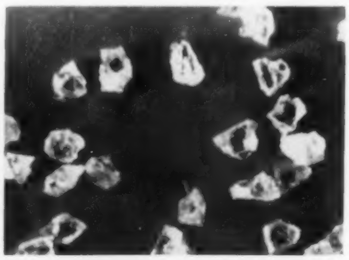
The product, designated PR-1460 and recommended for use in electrical equipment, is said to provide a positive seal against dirt and moisture. It is a high solids, two-part compound based on a liquid polysulfide rubber. The base material cures at room temperature to a solid rubber when mixed with an accelerator.

KEY NO. 650

Ceramic Powders Used in Hot Tooling

Corning Glass Works, Corning, N. Y. has developed two ceramic powders for use in hot tooling applications. The powders require no separate firing, and dimensions of parts made of the powders remain stable in use. Parts made of the powders can be machined and ground.

First applications are expected to be tools, jigs and fixtures for use in the aircraft and missile industry where shaping of exotic metals re-



Natural diamond grit—A new type of natural diamond grit, especially suited for use in metal-bonded cutting and grinding tools, has been developed by Diamond Research Laboratory, Johannesburg, South Africa. The grit is produced by a new selecting process in which weak and friable diamond particles are removed. According to the developer, the grit has been found stronger than any diamond grit so far available. In cutting concrete, marble, tile and similar abrasive materials with the grit, a 30 to 50% faster cutting rate was achieved than has been previously possible.

What's new IN MATERIALS

quires great heat and pressure.

Corcast is a hydraulically bonded petalite. Shapes are formed by casting, and no additional work is required to put a piece in service.

Service temperature of the ceramic powder is 2500 F, thermal conductivity is 0.723 Btu/ft/°F/hr, density is 110 lb per cu ft, and compressive strength is 2000 to 3000 psi. **KEY NO. 619**

Cortamp is a multi-bonded zircon. Shapes are formed by compaction. They are held together initially by an organic bond which shifts to a chemical bond at 1300 F, and to a ceramic bond at 2700 F.

Corning says the coefficient of thermal expansion of Cortamp remains close to 3×10^{-6} per °F throughout the bonding stages. Negligible shrinkage (0.3%) occurs during the shift from chemical to ceramic bonding.

Service temperature of Cortamp is above 4000 F, thermal conductivity is 1.08 Btu/ft/°F/hr, density is 200 lb per cu ft, and compressive strength is 10,000 to 12,000 psi.

The powdered materials are available in 100 lb packages. Cost is said to be competitive with chemically bonded materials. **KEY NO. 620**

Polyethylene Castings Resist Moisture, Heat

A one-part polyethylene copolymer casting resin is designed as an electrical insulation for microwave and other electronic devices.

The developer, Emerson & Cuming, Inc., 869 Washington St., Can-

***Electrical insulation** made of new polyethylene casting resin can be used at temperatures above 225 F.*

FOR SHEER, SHEAR STRENGTH

Hydraulic Pressure tests on Bridgeport Brass Company's patented cladding system show perfect no-leak bonds over 3000 psi.

...Bridgeport Brass Uses EASY-FLO 45 to Bond Their Clad Metals

The "thick and thin" of cladding—from .010 to 2¾" in a combination of ferrous and non ferrous metals—calls for a bonding agent that will hold under the most severe forming and service operations. The answer, in every respect, is Handy and Harman's silver brazing alloy, EASY-FLO 45.

The uses to which these clad metals are put range from the kitchen to power plants, refineries, chemical and food-processing installations. Famous Bridgeport Copperware, used by housewives throughout the country, is made from a triple-clad metal consisting of a sandwich of two sheets of .010 stainless steel bonded to both sides of a sheet of .025 copper. The metals are joined in Bridgeport's patented process at *finish gauge*. So strong is the bond that no difficulty is encountered in the forming operations which follow.

Tube sheets, though their uses are far from "domestic," require the same "bondability." Tests at Bridgeport show that shear strength exceeds 20,000 psi. And this involves the cladding of carbon steel to as many different metals as stainless, brass, Monel and copper.

The primary need here, of course, is strength. EASY-FLO 45 has other attributes that are more than welcome under *any* metals-joining conditions: thermal and electrical conductivity, gas- and liquid-tightness, ductility, ease of application and economy are some more that we'd like you to know more about. We are ready indeed to further acquaint you with the significant benefits of silver alloy brazing by sending you our Bulletin 20, which is a clear and comprehensive introduction to one of the simplest, *saving* metals-joining methods in existence. Handy & Harman, 82 Fulton Street, New York City 38.

Your No. 1 Source of Supply and Authority on Brazing Alloys

HANDY & HARMAN

General Offices: 82 Fulton Street, New York 38, New York

For more information, turn to Reader Service card, circle No. 442

What's new IN MATERIALS

ton, Mass., says cured castings can be used at temperatures above 225 F. The material, designated Stycast TPM-5, is also said to have good moisture resistance.

Castings made of the material are said to have physical and electrical properties similar to those of high density polyethylene.

KEY NO. 621

Silicone Fluid Controls Urethane Cell Structure

A new silicone fluid is said to produce a small and uniform cell structure in polyurethane foams. The fluid, called XF-1034 and developed by General Electric Co., Silicone Products Dept., Waterford, N. Y., is designed specifically for one-shot polyether flexible foams and Freon-blown rigid foams.

PROPERTIES OF XF-1034

Viscosity, cs	900
Viscosity-Temperature Coefficient	0.83
Specific Gravity	1.02
Refractive Index	1.4454
Flash Point, F	500
Fire Point, F	520
Pour Point, F	—15
Surface Tension, dynes/cm	26.8

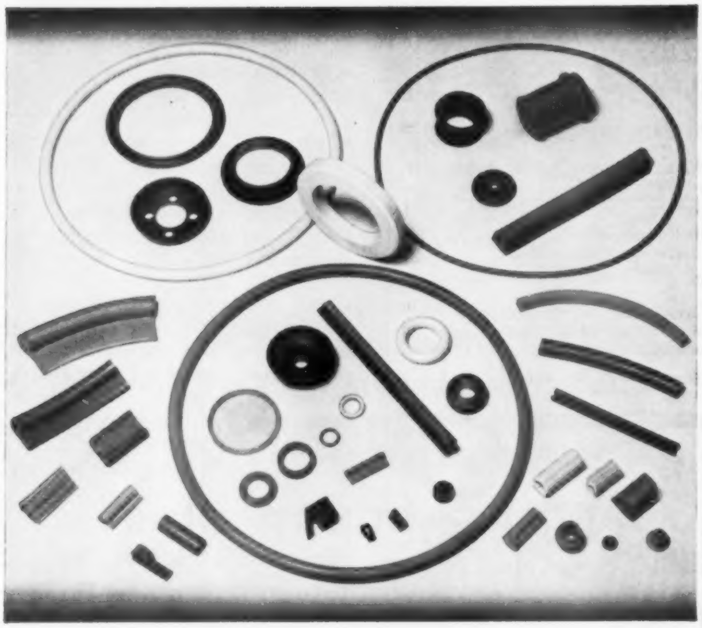
The fluid, presently available in developmental quantities, is a dimethyl polysiloxane-polyoxyalkylene copolymer. It is water soluble.

KEY NO. 622

Contoured Honeycomb Resists Heat, Stresses

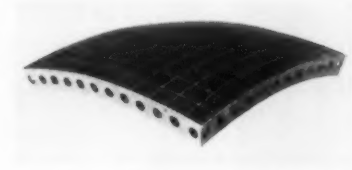
A contoured, all-metal honeycomb structure, now available, may be the answer to severe stress and heat problems encountered in high flying, high speed aircraft, missiles and space vehicles. The honeycomb is made by a new process in which contoured metal structures can be made in a variety of shapes and sizes. Processing details have not been disclosed.

The developer, Allied Research & Engineering Div., 6916 Santa Mon-



For more information, turn to Reader Service card, circle No. 352

What's new IN MATERIALS



Contoured honeycomb *can be made in a variety of shapes and sizes.*

ica Blvd., Los Angeles 38, Calif., says the honeycomb is presently being made of a high purity nickel.

Skin and cell walls can be as thin as 0.0005 in. Thickness of the skin is said to have no bearing on cell wall thickness, or vice versa. For example, a cell wall thickness of 0.0005 in. is entirely compatible with a skin thickness of 1/16 in., according to the producer.

The new product can be made with load-bearing inserts, mounting brackets, etc. Cell size can be varied to provide optimum strength-to-weight characteristics. The honeycomb structure can be welded by conventional techniques.

KEY NO. 623

New ABS Plastic for Injection Molded Parts

An easy processing, high gloss ABS (acrylonitrile – butadiene – styrene) plastic, now available, has been designed specifically for injection molded and sheet consumer products such as appliance housings, automotive trim, radio cabinets, telephones, sporting goods and small wheels.

The new thermoplastic is a product of Naugatuck Chemical Div., U. S. Rubber Co., 1230 Avenue of the Americas, New York 20.

Easily molded

Tests show that the material, called Kralastic MH, can be injection molded at faster speeds than conventional ABS plastics, and at approximately the same molding speeds of such plastics as cellulosics, impact styrenes and polyolefins. The material also processes well in vacuum forming and sheet extrusion operations.

The developer says molded parts can be machined, drilled, painted,

What every designer should know about...

High nickel alloy cold wound springs for high temperature service

When made of suitable materials, particularly the age-hardenable alloys, cold-wound springs will provide somewhat higher mechanical properties and design stresses than those obtainable in hot-wound springs.

The heat treatments used for the nickel alloys, other than triple heat-treated Spring Temper Inconel "X"*, are such that distortion during aging or stress relieving is minimal. For triple heat-treated Inconel "X" springs it is necessary to mount springs on a heat-resisting mandrel to avoid distortion.

All of the high-nickel alloy springs retain outstanding spring characteristics at sub-zero temperatures down to –320° F or lower. Some increase is imparted to tensile and shear properties with no significant or adverse effect on elongation or impact properties.

The nickel-copper alloy "K" Monel* and the nickel-chromium alloys Inconel* and Inconel "X" are non-magnetic and the cold work resulting from cold drawing to spring temper or cold winding have no adverse effect on their low permeability.

The nickel-magnesium alloy "Permanickel"* has the highest electrical conductivity of all of these high-nickel alloys and as a result has found useful application for springs of limited current-carrying capacity.

Grain coarsen annealing of Spring Temper Inconel and No. 1 Temper Inconel "X" has been found to significantly improve resistance to relaxation at elevated temperatures.

One of the outstanding characteristics of Inconel and Inconel "X" is their resistance to relaxation at elevated temperatures, at design stresses, corrected for curvature, that will permit useful designs without consuming excess space.

A useful guide for selection of materials for elevated-temperature service is shown below.

GUIDE FOR USE OF NICKEL ALLOY COLD WOUND SPRINGS[1]

Alloy	Temper	Heat Treatment[3]	Service Temp-°F	Stress; 1000 psi[4]
Monel* Ni-Cu	Spring	Str. Rel.	Up to 450	60-40
"K" Monel* Ni-Cu	Spring	Aged	Up to 500	65-50
Duranickel* Ni-Al	Spring	Aged	Up to 600	70-60
Permanickel* Ni-Mg	Spring	Aged	Up to 600	70-60
Inconel* Ni-Cr	Spring	[2]Str. Rel.	Up to 750	75-60
Inconel "X"* Ni-Cr	Spring	Aged	Up to 700	100-85
Inconel "X"* Ni-Cr	No. 1	[2]Aged	Up to 1000	70-45
Inconel "X"* Ni-Cr	Spring	Triple H.T.	900 to 1200	55-30

1. Wire sizes up to 7/16 to ¾ diam., depending on material and spring index.

2. Grain coarsen annealed prior to final cold draw.

3. Will vary depending on alloy, temper and end use — consult revised Technical Bulletin T-35.

4. For elevated-temperature service, lower stresses applicable to higher temperatures — consult T-35.

Inconel and Inconel "X" alloys have outstanding resistance to high purity waters containing chlorides, to hot fatty acids and most neutral and alkaline salt solutions. The alloys remain bright indoors indefinitely.

In many cases Inconel and Inconel "X" offer cost advantages, both hot and cold wound, over high alloy steels for springs intended or elevated-temperature service.

Helpful New Technical Bulletin T-35, "High Nickel Alloy Helical Springs" gives newly-developed information on test methods for relaxation; relaxation data and recommended stresses; effects of grain coarsen annealing; triple heated Spring-Temper Inconel "X" for service up to 1200° F; and hot forming practices. Write today for newly-revised Technical Bulletin T-35.

*Inco trademark

HUNTINGTON ALLOY PRODUCTS DIVISION
The International Nickel Company, Inc.
Huntington 17, West Virginia

INCO ALLOY PRODUCTS

TRADE MARK

For more information, turn to Reader Service card, circle No. 448

What's new IN MATERIALS

metallized, cemented and nailed.

Properties

The new plastic is said to withstand continuous exposure to temperature up to 185 F. It is also said to have good abrasion, mar and chemical resistance.

KEY NO. 624

Graphitized Lubricant Resists Heat, Pressure

Perma-Slik is the name given to a new graphitized molybdenum disulfide lubricant supplied in a sprayable suspension. The developer, EverLube Corp., 6940 Farmdale Ave., North Hollywood, Calif., says the lubricant stays bonded to surfaces at temperatures from -300 to 500 F and at pressures up to 50,000 psi. The lubricant, unlike other molybdenum disulfide suspensions, will not wash off.

The product is recommended for use in office equipment, automotive parts such as valve stems, pistons and camshafts, and bakery equipment. It can be applied to steel, copper, brass, nickel, aluminum, magnesium, plastics and wood.

KEY NO. 625

Glass Shapes for Filler, Packing Uses

Low cost glass pillows and balls are commercially available from Corning Glass Works, Corning, N. Y. for use in filler, packing, filtering and tumbling applications.

The glass pillows are supplied both solid and hollow in lengths up to ½ in. The balls are supplied solid in diameters up to ½ in.

The hollow pillows are said to provide a low density filler material for such applications as packing in aircraft wings where the glass gives both structural support and buoy-

PROPERTIES of most engineering materials can be found in the third edition of M/DE's *Materials Selector* reference issue, published last October. Names and addresses of suppliers are also listed.

the LEAD newsletter

Vol. 2 No. 2

Lead Antennas

During the Korean War, Helicopter design engineers were stumped with the problem of finding space for the radio antennas for rescue helicopters. A stretched wire antenna seemed to run afoul of something no matter where it was placed on the craft. Lead tape saved the day. Adhesive backed, the tape could be stuck to any convenient member of the frame. A single bolt through the tape and its supporting surface (insulated from metal parts, of course) clamps the electrical lug in place to complete the antenna.

The call for help that brought this Bell Rescue Helicopter was received with a lead tape antenna.

Rotor Blade Test

Nor is lead tape confined to flying helicopters. Kaman Aircraft Corporation uses it to find the balance point of rotor blades at various pitch angles. Thin enough to not change critical contours, the tape nonetheless packs enough heft to be handy in prototype testing. Though the tape is replaced by metal structural members before any aircraft is used or sold, it does save time in making on-the-spot quick weight changes in the exact increments required.

Lead Masking Tape

Turco Products' new chemical milling process employs powerful etchants to remove the metal of the complex shapes it produces. Since it is so fast and easy to apply, lead tape is a time-saver here, too. It can be trimmed to a clean, sharp outline. It resists the etching solution. It has become a handy adjunct to other masking materials—especially to cover pinholes and mask edges.

Oilless Bearing for −328° to +536°F. Operation

Bearings that require no oil, grease, graphite, or any other applied lubrication have long been a designer's dream. This dream is now a reality. Developed by the British and called DU, this bearing material is available in the U.S. from the United States Gasket Company.

DU combines the well-known excellent bearing properties of lead with the ultra-low coefficient of friction of TFE fluorocarbon plastics. A mixture of lead and TFE powders is impregnated in a fine porous bronze skeleton which provides high heat conductivity to keep the bearings cool. Tin-plated steel backs up this combination. The result is a bearing material with low friction characteristics, very low wear, and high compressive strength. DU bearings endure intermittent operation at 40,000 psi compressive load where ball races had previously failed.

And that's not all. DU bearings have operated successfully at −328°F. and as high as 536°F. Quick, wide changes in temperature cause no difficulty either. Although new, DU has already found many applications. Among them: jet engine air intake vane bearings, landing gear and control rod bearings, and in automobiles in the electric starter motor, generator, steering column and other locations.

Lubrication for 1250°F. Service Developed at NASA

An effective lubricating system for use up to 1250°F. ambient temperatures has been developed at the NASA Lewis Research Center in Cleveland, Ohio. A bonded lead oxide film was the answer here. Applied in the manner of porcelain enamels to stainless steel (type 440C), the film consists of PbO, 5% SiO_2 and about 5% Fe_2O_3 absorbed from the steel during firing.

Compared to commercial resin-bonded type molybdenum disulphide coatings, the PbO films provided superior wear and lower friction coefficients above 600°F. These coatings operate best at high temperatures and high sliding velocities. In fact, at sliding velocities from 2,400 to 10,000 ft. per min. the friction coefficients were practically constant ($F = 0.05$ to 0.08) at all temperatures studied.

As ambient temperatures are increased, endurance life is found to increase and approaches a maximum at about 1,000°F, then decreases slightly at 1,250°F. Although other lubricants are superior below 600°F, these coatings have satisfactory properties in the low temperature range so that they can be used in operations which start at low temperatures before coming to the higher operating temperatures.

Permanent Color for Lightweight Building Block

An important new addition has been put in the architect's bag of tricks by Zonolite Company—*glazed* lightweight aggregate building blocks. These lightweight blocks are permanently waterproof, permanently colorful. And since both interior and exterior walls are glazed, they are both finished and ready for use without further protection or decorating.

The blocks are a reality because of Lead's ability to promote glaze-body reactions, control viscosity, and produce a low surface tension, all at low firing temperatures. A wide variety of textures can be produced from rough and matte to smooth and glossy, even over the rough texture of the block itself.

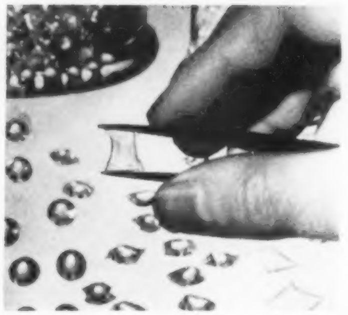
If you would like information or technical assistance on new lead developments and applications, write to: Office of Technical Information, Lead Industries Association, 292 Madison Avenue, New York 17, N.Y. 2629

LOOK AHEAD WITH LEAD

For more information, turn to Reader Service card, circle No. 328

ancy. They can also be used as a filler material in the casting of large plastics parts.

The solid pillows can be used as fillers in refractionating columns and in filter beds. Also, their tumbling action is said to provide the necessary agitation in electroplating operations. **KEY NO. 626**



Hollow pillows *(foreground), solid pillows, and ball-shaped glass pieces can be mass produced in uniform shapes and sizes.*

Stabilized Plastics Resist Weathering

Longer lasting polyethylene and polypropylene plastics for outdoor applications are promised with two new products.

One is a non-pigment type, light absorbing chemical compound developed by American Cyanamid Co., 30 Rockefeller Plaza, New York 20. The other is a light stabilized polyethylene formulation developed by Eastman Chemical Products, Inc., 260 Madison Ave., New York 16. Both products are commercially available.

A big advantage of the two products is that clear or pigmented polyethylene and polypropylene can be made for outdoor applications. Previously, carbon black was used to light stabilize these resins.

1. Chemical stabilizer

Cyanamid's chemical compound, called Cyasorb UV 314, is designed specifically for light stabilizing polyethylene and polypropylene plastics. Tests showed that polyethylene stabilized with Cyasorb UV 314 retained up to 88% of its initial elongation after four months' exposure to severe sun conditions in Arizona.

Marine ropes and fabrics for automotive upholstery and lawn furniture are some of the products that might be made with light stabilized polyethylene or polypropylene fibers, according to Cyanamid. Film and sheeting applications might include greenhouse sheeting, tarpaulins and high altitude balloons. **KEY NO. 627**

2. Stabilized polyethylene

Eastman Chemical's stabilized polyethylene formulation (Tenite) incorporates a non-pigment type of ultraviolet inhibiter that is added to the resin during production.

According to the company, extruded film 5 mils thick has withstood two years of weathering with little loss of strength. Laboratory tests showed that the stabilized polyethylene film retained more of its original properties after 24 months' exposure than unstabilized polyethylene film retained after 12 months' exposure under the same environmental conditions.

(continued on p 190)

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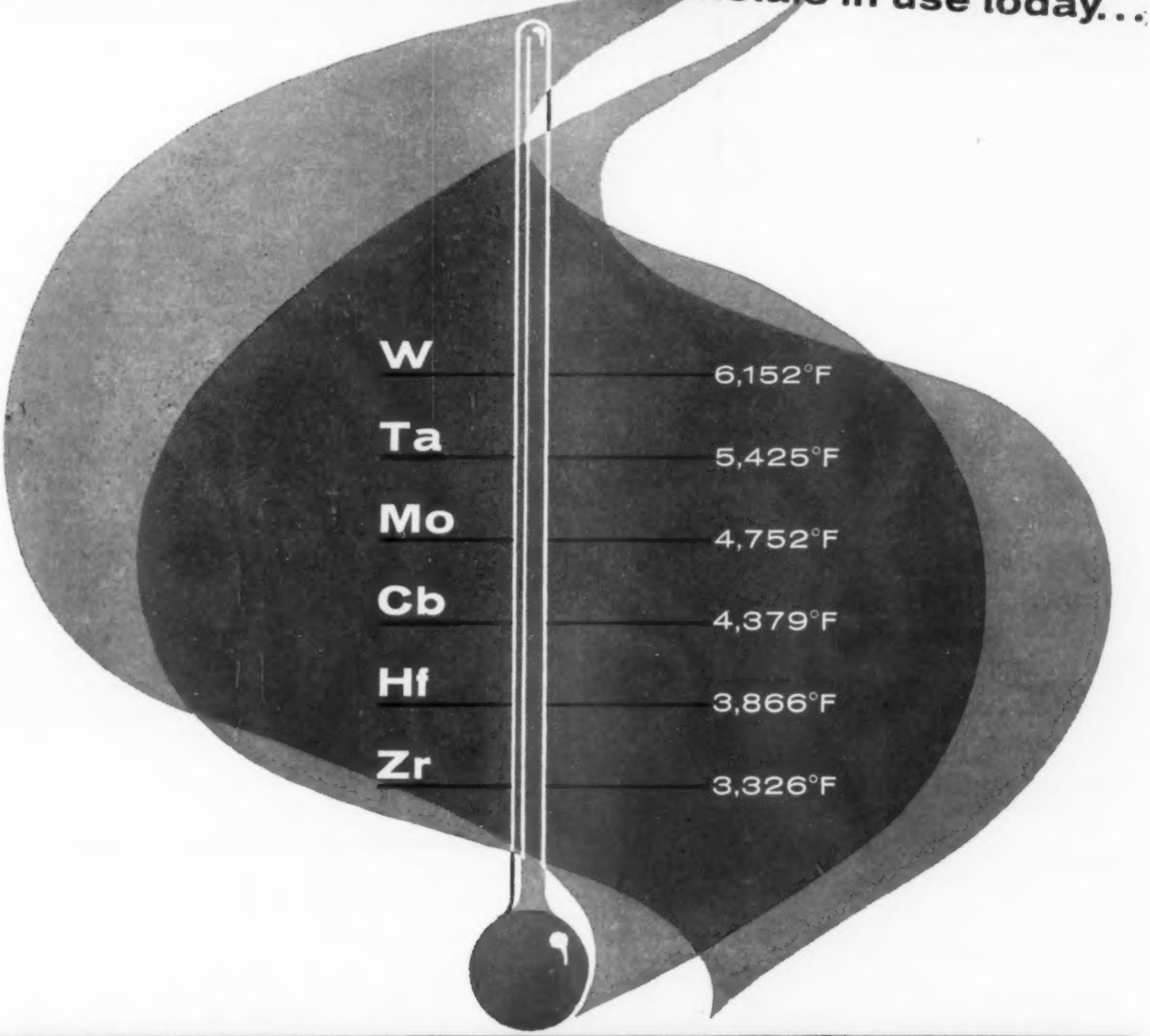

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233 Broadway
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For more information, turn to Reader Service card, circle No. 445

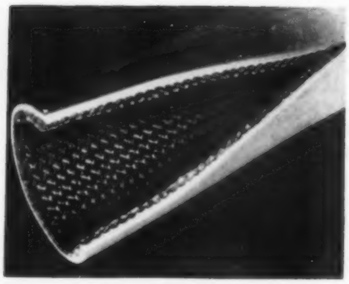
What's new IN MATERIALS

In weathering tests recently completed, a 50-mil thick sheet of the material showed a retention of 88% of its initial elongation after three years' outdoor exposure. Heavier sections ⅛-in. thick, weathered under stress, retained their good appearance after five years.

Eastman Chemical supplies the stabilized polyethylene formulation for extrusion as thin film at a price premium of 5¢ per lb. It also supplies the material for injection molding for extrusion of sheet 50 mils thick or greater at a price premium of 2¢ per lb. **KEY NO. 628**

Insulation Resists Assembly Damage

A silicone rubber-coated braided fiberglass insulating sleeving is said to resist fingernail damage and similar product assembly hazards.



Cross-sectional view *of new insulating sleeving made of silicone rubber-coated braided fiberglass.*

Called Ben-Har 1151, the product is available from Bentley-Harris Mfg. Co., Conshohocken, Pa.

The developer says the electrical insulating sleeving expands four sizes larger than its original diameter, fitting easily over irregular connections without end fraying or coating fracture.

The product is said to meet specifications for electrical insulating sleevings covered by MIL-I-18057A and NEMA Type 5. The product is rated for continuous operation at 430 F. Its low temperature brittle point is below −120 F. **KEY NO. 629**

Polyethylene Bonds to Oxide-Coated Metals

A good way to bond polyethylene to copper or copper-plated metals is to mold the material directly onto a cupric oxide-coated metal surface, say scientists at Bell Telephone Laboratories, 463 West St., New York 14.

Bonds formed are said to have strengths between 20 and 40 lb per in. of width; best previous efforts gave strengths of 5 to 10 lb per in.

Metals coated

Low, medium and high density polyethylene and ethylene-butane copolymers have been successfully bonded to high copper alloys (85% or more copper), beryllium copper, and phosphor bronze.

Cupric oxide layer key to good bonds

Key to the new bonding process is the chemical formation of a cupric oxide layer on metal. The oxide layer is formed by cleaning the surface of a metal with acid, then treating it with a sodium chlorite-sodium hydroxide solution.

The cupric oxide surface oxidizes the polyethylene surface and adds polar sites (functional groups such as hydroxyl and carbonyl) that

BEE

FINISHES • COATINGS • PLASTISOLS

ZENITH SPECIFIES NEW LOGO W-III BAKING FINISH FOR DIE-CAST TV BEZELS

Take a close look at the bezels of 1960 model TV sets by Zenith Radio Corporation, Chicago. The finish is LOGO BRONZELESS GOLD colored W-111, BEE's new sprayable, hard, mar-resistant baking finish developed for metals and thermosetting plastics.

W-111's outstanding durability has been tested by Zenith with their famous "shaker test." Zenith placed the BRONZELESS GOLD coated TV bezels in cartons, separated by cardboard liners, just as they would be shipped to Zenith by its suppliers. The vibrating machine then put W-111 through the "shakes" for a period of 30 minutes. This approximates 2500 miles in rail transit with the cartons placed directly over the wheel trucks of the box car. (Ask your own traffic manager about the abrasive power of cardboard liners!) The bezels rolled in clean with no evidence of abrasion.

The BRONZELESS GOLD coated bezels can boast resistance to a host of other enemies. In 24-hour spot tests with iodine, mustard, vinegar and such other agents as appliance surfaces have to put up with daily, no staining occurred. Soaps and detergents also showed no effect. W-111 has 4H to 6H pencil hardness. The handling and color control capabilities of W-111 also make it easy to live with.

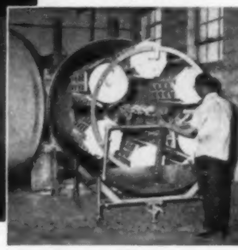
Adhesion is excellent even on zinc die castings with no pretreatment other than normal cleaning!

A leading manufacturer of heating and air conditioning equipment (name on request) put bonderized cold roll steel parts coated with W-111 through an extensive salt spray test. W-111 passed in excess of 200 hours' exposure.

In a clear form W-111 is applied by hand or automatic spraying. It is used as a dipping material for the protection of brass and brass-plated steel against corrosion.

Its impermeability, durability and high gloss will stand it in good stead for appliance use wherever exceptional hardness and mar resistance are desired. We are ready to make additional promises for W-111 on specific applications and to send you a product information sheet: the coupon on this page will do the trick.

VACUUM METALLIZING: BRIGHT FUTURE IN THE AUTOMOTIVE FIELD



Acrylic housings for tail lights, back up lights and parking lights are replacement parts vacuum metallized by B & T Plastic Finishing Co., Evanston, Illinois.

With the cost squeeze ever-tightening, Detroit and its legion of suppliers are looking harder than ever at vacuum metallizing—a highly effective, economical finishing process that competes as a decorative finish with chrome plating for both interior and exterior parts.

You'll see v.m. on a good many new models without ever knowing the difference; for example, on plastic parts for the dash and steering wheel sections.

If you have one of yesteryear's models and need a replacement for a smashed tail light or back up light housing you'll get vacuum metallizing in the form of a molded acrylic housing that has been metallized on certain areas to simulate a chrome ring or, with some makes, the whole housing will have the mirror-bright finish of v.m. . . . In this application the parts have been metallized on the second surface. The thin metallic film of aluminum shines through the clear acrylic with the brightness of chrome. This film is protected by a sprayed back up coating.

Briefly, the vacuum metallizing process consists of coating the plastic or metal object with a resin or lacquer known as the base coat. This coating is then baked. A metallic film (aluminum is most widely used) is then condensed directly on the base coat in a chamber under high vacuum. The part is then coated with a top coat which is either clear (for a chrome or silver effect) or pigmented to simulate gold, brass, copper or other metallic colors.

BEE CHEMICAL COMPANY supplies base coats, top coats and back up coats to metallizers for application by spraying, flow coating or dipping. Each LOGO System is designed for a specific surface under specific conditions and perfected to give the required functional properties as well as desired decorative effects.

If Vacuum Metallizing sounds like the knock of opportunity for your product there's no need to concern yourself with the mechanics of this process. *BEE is ready to assist you in finding a dependable, local source for your metallizing needs.* Use the coupon to tell us of your interest and we'll do the rest.

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TRADE MARK

For more information, turn to Reader Service card, circle No. 449

What's new IN MATERIALS

sharply increase the adhesive action between metal and plastic.

Potential uses

The developer says the new process can mean advances in flexible printed circuits, microwave devices, and other electronic devices where the excellent dielectric properties of polyethylene can be put to good use.

Zinc-Type Coating Protects Columbium

An effective way to protect columbium metal against oxidation at temperatures up to 2200 F is by using a new zinc-type coating developed by the U. S. Naval Research Laboratory, Washington, D. C. (see M/DE, Mar '60, p 5).

Self-healing ability

Probably one of the biggest advantages of the coating is its self-healing ability; an opening in the coating is rapidly covered with a thin layer of oxides.

The coating, still under development, consists of layers of intermetallic zinc-columbium compounds on the surface of the metal. The intermetallics are formed by dipping columbium metal in molten zinc. The zinc coating is then reacted with the columbium substrate by annealing in air at 1600 F. Annealing also causes layers of zinc oxide and zinc-columbium oxide to form on the surface.

According to G. Sandoz of the Naval Research Laboratory, the coating can be dislodged from columbium only with great difficulty.

Good oxidation resistance

Sandoz, who described the coating in the Apr '60 issue of the *Journal of Metals*, says preliminary tests showed no oxygen absorption in coated columbium specimens after 5 hr exposure to hydrogen combustion products moving at 500 ft per sec at a temperature of 2000 F. Uncoated control specimens, on the other hand, were completely converted to oxides in 3 hr at 2000 F.

Plastics Products for Molding, Insulating

Three new plastics products have been introduced recently by Rogers Corp., Rogers, Conn. Two are phenolic molding compounds, and one is a cellulosic sheet material for electrical insulation.

1. Phenolic compounds

RX 525 is the name given to an improved type of impact phenolic molding compound that can be molded under low pressures. In one application the molded material withstands the shock produced by automatically driving 128 pins into the material.

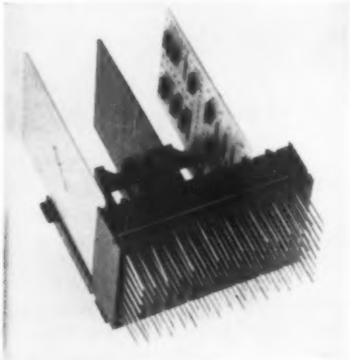
The other phenolic molding compound is an asbestos-reinforced material with a heat distortion point of over 500 F. It is designed

PROPERTIES OF RX 495

Mold Shrinkage, in./in.	0.001
Tensile Strength, psi	6000
Compressive Strength, psi	22,000
Impact Strength (Izod Notched), ft-lb/in.	2.5
Arc Resistance, sec	165
Ignition Time, sec	340

What's new IN MATERIALS

primarily for gears, electrical switchgear and control parts. The reinforced phenolic, called RX 495, is said to mold to a high luster finish. The material can be used on transfer and compression molds involving intricate details. It is said to produce parts with exceptionally good appearance. KEY NO. 631



Phenolic compound *is used for printed circuit receptacles in a business machine.*

2. Cellulosic insulation

A flame retardant version of the company's cellulose fiber-resin insulating material (Duroid 225) is said to extinguish itself in well under five seconds as specified by Underwriters Laboratory. The material, called Duroid 225 FR, is a sulfate pulp material treated by a beater addition method so that the cellulosic fibers are encapsulated in a polymeric resin. The material is supplied as sheets in thicknesses of 0.031, 0.062, 0.093 and 0.125 in. KEY NO. 632

Other News . . .

Metals

▶ Vanadium Corp. of America, 420 Lexington Ave., New York 17 has announced a new alloy for introducing manganese into wrought aluminum alloys. The material is called Low Iron Manganese. KEY NO. 633

▶ A new copper tube designed especially for refrigeration and air conditioning applications is available from Wolverine Tube Div., Calumet & Hecla, Inc., 17200 Southfield Rd., Allen Park, Mich. The product, called ACR, Type L, is a cleaned and sealed tube supplied in 20-ft straight lengths in sizes ranging from ¼ to 4 in. o.d. KEY NO. 634

▶ Viking Wire Co., Inc., P. O. Box 104, Danbury, Conn. has introduced a 50-gage AWG magnet wire insulated with a single coat of enamel. The insulated wire is designed for use in hearing aid transformers, miniature relays, computers and syncro motors. KEY NO. 635

Plastics

▶ An improved synthetic fiber-reinforced TFE gasket material developed by American Felt Co., Glenville, Conn. is said to have excellent resistance to acids, alkalis, aliphatic and aromatic compounds, and corrosive gases at low and high temperatures. The material, called Vistex Type NS-NES, is supplied as sheets 30 by 60 in., in thicknesses from 1/64 to 1/8 in. KEY NO. 636

▶ A copper-clad plastics laminate that is said to have excellent punching and electrical characteristics has been introduced by Taylor Fibre Co., Norristown, Pa. Called Grade 320, the phenolic-paper laminate has high

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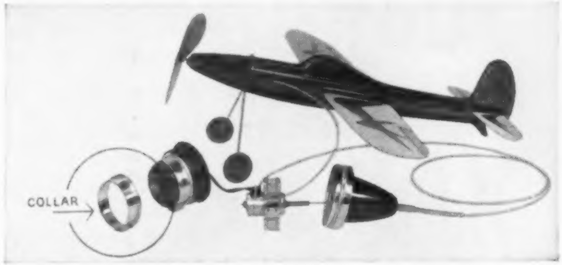
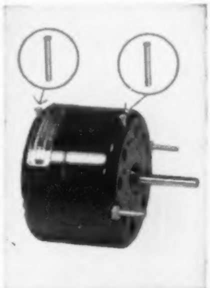
For more information, turn to Reader Service card, circle No. 392

IDEAS for cutting costs . . .

ELIMINATE THREADING OPERATION. Barrel of a small keycase flashlight required separate threading operation to accommodate cap. Fabricated Metal Goods Division engineers suggested three indentations to replace female thread so aluminum barrel could be completely fabricated on our multiple-plunger presses—cutting out cost of second operation.



LOW-COST COLLAR. Toy maker needed a large flat-flange collar to act as stop and contact for switch and to conduct current from batteries to motor operating toy plane. Using experience in making eyelets, our engineers designed a precision aluminum part we could make on a multiple-plunger press. The part simplified assembly, served electrical and mechanical functions—had a very attractive price.



EYELET FOR OIL FEED. Motor manufacturer was making oil-feed tubes by cutting short lengths from seamless tube and flaring one end—and having some trouble in assembly with square-cut end. Our engineers designed a funnel-flange eyelet to the specified dimensions—with a radius on unflanged end to simplify assembly. Because we made the part on a multiple-plunger press, metal gage could be reduced. Total savings were very considerable.

Maybe we can develop cost-cutting ideas for you, too. We offer a complete design-engineering service based on long experience and specialized production equipment. Write for Booklet BG-5. Better yet, send a sample, drawing, or description of a part you need to produce at low cost (any metal, any finish) for an eye-opening quotation. Address: Fabricated Metal Goods Division, The American Brass Company, Waterbury 20-A, Conn. 60178

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insulation resistance, low dielectric loss, and good dimensional stability. It is supplied in sheets 36 by 48 in. **KEY NO. 637**

▸ A pressure sensitive plastics laminate has been introduced by Fasson Products, 250 Chester St., Painesville, Ohio for decorative applications. The material consists of a layer of polyester film laminated to vinyl. It is supplied in rolls, strips and sheets. **KEY NO. 638**

Other nonmetallics

▸ A wood veneer laminate surfaced with Videne polyester film is being marketed by Wilcox-Woolford Corp., Spring City, Pa. The product, called Furnadene, is made with a variety of woods in 4 by 8 ft panels. **KEY NO. 639**

▸ Resin-treated crepe paper for forming wire guides, protective coverings, supports and other electrical parts is available from Westinghouse Electric Corp., Micarta Div., Trafford, Pa. According to the producer, the material stretches as much as 200% when used to form straight, curved and angular channels with various degrees of taper. **KEY NO. 640**

▸ Sleeve bearings lubricated with a new self-wicking lubricant introduced recently by Permawick Co., 5319 E. Outer Dr., Detroit 34 are said to perform satisfactorily at continuous temperatures up to 200 F under high loading. The developer says size of bearing reservoirs can be substantially reduced with this lubricant. **KEY NO. 641**

Finishes

▸ A new epoxy-base pipe coating developed by Minnesota Mining & Mfg. Co., 900 Bush Ave., St. Paul 6, Minn., can be directly applied to hot pipes as they emerge from fabricating equipment. The coating is called Scotchkote. **KEY NO. 642**

▸ A cold-applied, rust inhibitive primer called Bitumastic 11-S is said to prevent surface contamination from attacking untreated metals. It is also said to prevent undercutting on coated surfaces. The product is available from Koppers Co., Inc., Koppers Bldg., Pittsburgh 19. **KEY NO. 643**

▸ A new line of fluidized bed plastics coatings is available from Michigan Chrome & Chemical Co., 8615 Grinnell Ave., Detroit 13. The coatings, called Miccron, are supplied in nylon, epoxy, cellulose and vinyl formulations. **KEY NO. 644**

Advertisers & Their Agencies

Use this index for the latest information on how and where to use **materials, forms and finishes** ... because more companies advertise these products in the thirteen issues of MATERIALS IN DESIGN ENGINEERING than in any other magazine.

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THE LAST WORD

For Martini Drinkers Only

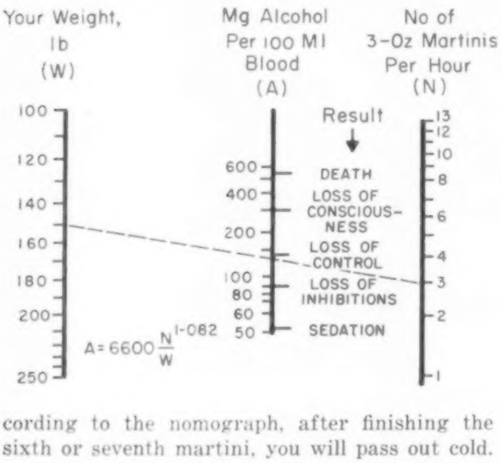
by H. R. Clauser
Editor

Somewhere I heard or read that more liquor is consumed in July than in any other month except December. So, I plunged into my bulging file of unused "Last Word" items and came up with the following appropriate items for this July column.

When will you pass out?

Below you will see a martini nomograph. Its rational approach should appeal to all irrational martini-drinking engineers. It was developed by a D. S. Davis and appeared originally in *Chemical Literature*.

The nomograph tells you what your condition will be after drinking a given number of 3-oz martinis per hour. For example, if you weigh 150 lb and drink three martinis within the span of an hour, you will become uninhibited and probably begin to stumble on that high step. If you double your intake to six or seven, the party will be a very short one indeed. For, according to the nomograph, after finishing the sixth or seventh martini, you will pass out cold. If you are unlucky and don't pass out, chances are that after the ninth or tenth martini you will pass out and on for good.



Are hangovers passing out?

There is some hope, though, for martini drinkers. The science of gas chromatography has found that gin and vodka are less likely to produce hangovers than whiskey. Two researchers for Perkin-Elmer, a chromatography instrument manufacturer, found that hangovers are caused by the small amounts of ingredients that give the liquor its flavor and odor. Since gin and vodka contain less of these trace ingredients, they have less flavor, less odor and produce less hangover.

This scientific knowledge on hangovers has encouraged the never-ending search for hangover-free whiskey. If such a drink is ever developed, scientists say it will probably have a base similar to vodka with the rye or bourbon flavor added synthetically.

Tired of martinis? Try 'scrap iron'

If you are tired of martinis or if you are one inclined to concocting weird drinks, you may be interested in one developed by Southern bootleggers. Nicknamed "scrap iron," the drink is composed mainly of rubbing alcohol and mothballs with small additions of yeast, cracked corn, sugar, and Chlorox. However, the drink is not really being recommended for either yourself or your friends. According to the report in the Journal of the AMA, "This is a drink of 'voltage' rather than 'vintage,'" and victims exhibit symptoms of acute mental disturbance "out of proportion to the amount of alcohol consumed."

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